PB86-216512

Underground Motor Fuel Storage Tanks: A National Survey. Vol. 1. Technical Report Vol. 2. Appendices

Westat, Inc., Rockville, MD

Prepared for

Environmental Protection Agency, Washington, DC

May 86

U.S. Department of Commerce
National Technical Information Service
NTIS

PB86-216512

United States
Environmental Protection
Agency

Office of Pesticides
and Toxic Substances
Washington, DC 20460

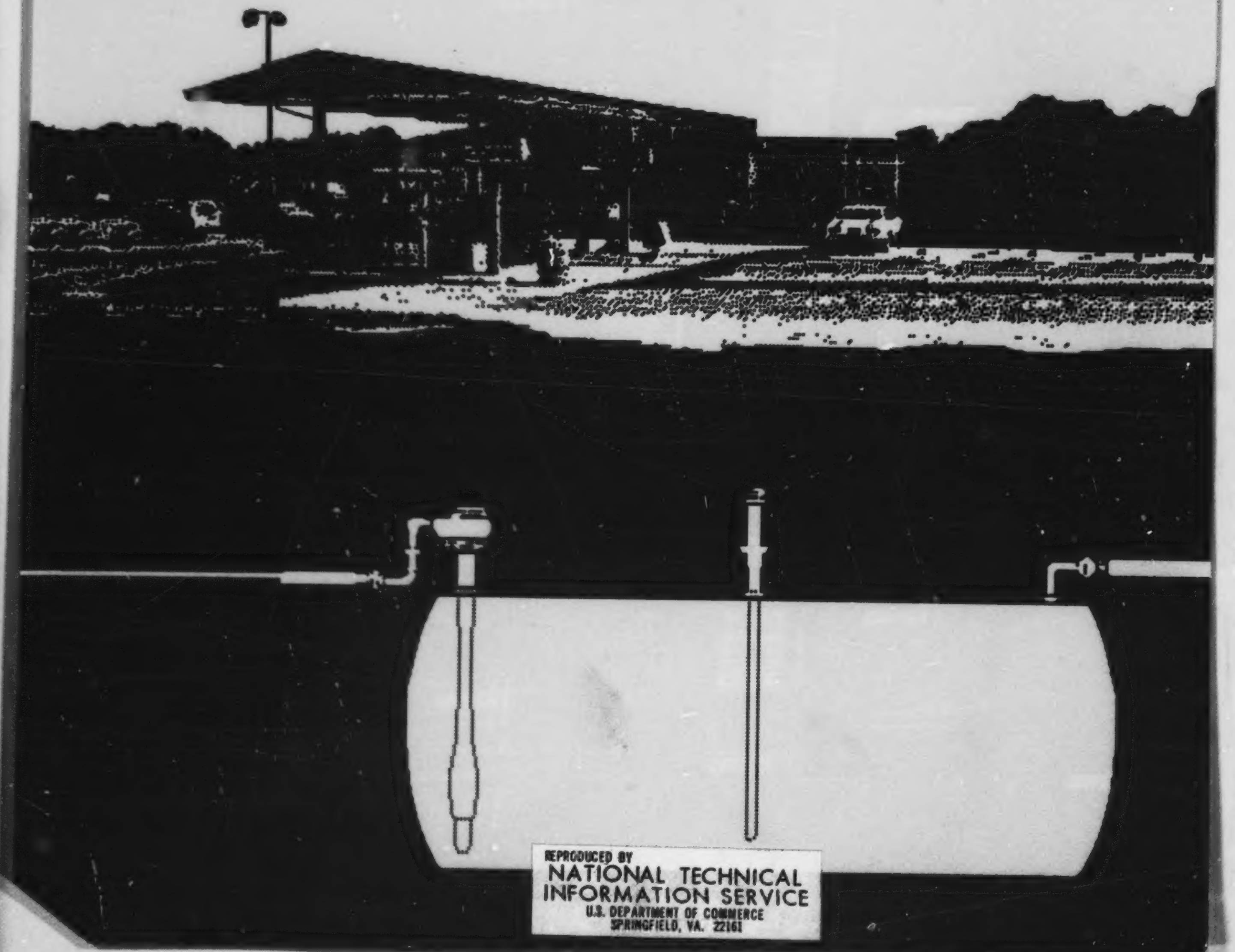
EPA 560/5-86-013
May 1986

Toxic Substances

EPA

Underground Motor Fuel Storage Tanks: A National Survey

VOL. I. TECHNICAL REPORT



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NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. EPA 560/5-86-013

2.

3. Recipient's Accession No. PB86 216512/AS

4. Title and Subtitle

Underground Motor Fuel Storage Tanks: A National Survey

5. Report Date May, 1986

6.

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10. Project/Task/Work Unit No. Task 3

11. Contract(C) or Grant(G) No.

(C) EPA No. 68-02-4243
and
(G) EPA No. 68-02-3938

12. Sponsoring Organization Name and Address

Environmental Protection Agency
Office of Toxic Substances
Exposure Evaluation Division
401 M Street, S.W.
Washington, D.C. 20460

13. Type of Report & Period Covered

Final Report
Feb. '84 - May '86

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

A nationally representative sample of 2,812 establishments were interviewed to determine the presence of underground motor fuel storage tanks. This sample represented establishments in fuel-related industries (1,612), large establishments in all other industries (600), and farms (600). A total of 890 of these establishments were found to have a total of 2,445 underground motor fuel storage tanks. Only 19 farms with 34 tanks were found. The following national estimates were made: there are 796,000 underground motor fuel storage tanks at 326,000 establishments in the Unisted States -- 158,000 of these are on 79,000 farms. A subsample of 218 establishments was selected for tank tightness testing, using a modification of a commercially available test. The method over-filled the tank system into a standpipe, and thus detected leakage anywhere in the system of tank vessel, pipes, lines, joints, and fittings. Among the non-farm establishments tested, the following estimates were made: 35 percent (189,000) of tank systems were judged to be leaking under test conditions; the average leak rate of those systems with quantifiable leak rate, adjusted for test pressure, was 0.32 gallons per hour; half the leaks among all systems judged to be leaking were 0.25 gallons per hour or less.

17. Document Analysis a. Descriptors

Establishment characteristics, leaking underground tanks, survey design, tank characteristics, tank establishments, tank tightness testing, underground motor fuel storage tanks

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement

19. Security Class (This Report) Unclassified

20. Security Class (This Page) 11

21. No. of Pages

22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

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May 1, 1986

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The research on underground storage tanks contained in this report represents the joint efforts of several organizations and many individuals. The project team met separately to refine the study design, analyses, and approach to data interpretation. The names of the principal authors and the contributions of the various organizations are summarized below.

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ACKNOWLEDGEMENTS

Many individuals contributed their time and effort to this very complex survey effort. Especially helpful and supportive at every stage of the survey was Martin P. Halper, Director of EPA's Exposure Evaluation Division. Valuable advice and input was provided by Steven E. Way and David O'Brien of EPA's Office of Solid Waste and Emergency Response. Support in obtaining cooperation from survey respondents was provided by M. Elizabeth Cox of EPA's Office of Enforcement and Compliance Monitoring. Senior statistical guidance on leak status estimation was provided by Morris H. Hansen and Benjamin Tepping of Westat. John Michael, also of Westat, provided guidance and review of regression and logistic modeling efforts. We wish to recognize the work of Annett Nold of EPA's Exposure Evaluation Division who, together with Debra Sarvela and Jon Chen of General Software Corporation, are responsible for Appendix H on soil data. Our thanks to Joan Blake of EPA's Exposure Evaluation Division for her work in summarizing the many peer reviewer comments and the final implementation of reviewer suggestions. There were many others in EPA's Exposure Evaluation Division and Office of Solid Waste and Emergency Response who provided valuable support and assistance at various stages in the survey. Finally, we would like to thank Sandy Gallagher and Joyce Jones for their long hours of word processing in preparing the final report.

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EXECUTIVE SUMMARY

Background and Objectives - The U.S. Environmental Protection Agency's Office of Toxic Substances (OTS) conducted a national survey of underground motor fuel storage tank systems. This study was conducted in support of the EPA's Office of Underground Storage Tanks, which has responsibility for implementing the requirements of the 1984 Amendments to the Solid Waste Disposal Act. The results of the survey are presented in this report.

The primary objectives of the national survey were to provide estimates of: (1) the total number of underground motor fuel storage tanks; (2) the number of establishments with underground motor fuel storage tanks; (3) the number of tanks that leak; and (4) characteristics of tanks and tank establishments. These tank and establishment characteristics were analyzed in a search for possible correlations with leak status (i.e., whether or not a tank system leaks) and leak rate. In addition, OTS conducted an evaluation of the use of inventory reconciliation analysis as an indirect method of detecting and measuring leaks.

Scope - The target universe included the following kinds of establishments if they had motor fuel stored in underground tanks: (1) fuel-related establishments, including business, government and military (establishments which store fuel for retail sales or transportation services including gas stations, trucking companies, auto dealers, marinas and other industry groups using or dispensing motor gasolines, diesel fuel, aviation gasoline, and jet fuel); (2) large establishments in non-fuel-related industries (establishments which store fuel for purposes such as company vehicles and private fleets); and (3) farms. The

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survey excluded: tanks storing heating oil, used motor oil, chemicals, hazardous wastes and sewage; tanks which are above or partially above ground, abandoned or nonfunctional tanks; private non-business tanks; bulk storage tanks; and tanks which do not dispense fuel to end users.

Data Collected - Survey data collection was conducted with a national probability sample of 890 establishments, with a total of 2,445 tanks. A subsample of 218 establishments was selected for physical tank testing, and at those sites there were 433 tank system tests that yielded conclusive results.

Three different primary data collection efforts were used in this survey. In-person interviews were conducted with tank establishment operators in order to collect a variety of information such as the type of business, type of fuel stored, number of tanks, and tank characteristics (such as capacity, age, material of construction). The second type of data collection involved fuel inventory data which were provided by establishment operators and analyzed to evaluate inventory reconciliation techniques as an indirect method of detecting and measuring leaks. The third data collection effort involved physical tank system tightness tests at a representative subsample of establishments.

Response Rate - A rigorous quality assurance program was implemented at every stage of the survey. Response rate for the interview with tank owner/operators was 99 percent, which is very high. The tank testing phase achieved an excellent cooperation rate of 95 percent; even after allowing for untestable tanks, the tank testing response rate remained at a high level of 85 percent. For the inventory data collection, 78 percent of those contacted provided complete or partially complete data. However, only 41 percent produced data that were sufficiently complete and accurate to be used in the inventory reconciliation analysis of this study.

Terminology - Several terms are important to the understanding of the survey's results and are thus defined here. The estimates apply to the tank system which includes the underground vessel together with all connecting distribution lines, vent and fill pipes and connections. Manifolded tank systems consist of two or more tank systems which are joined together. Whether or not a tank system passed the tightness test is determined by a statistical decision rule applied to the physical measurement data. This decision rule involves the null hypothesis that the tank system is tight. This test has a 5 percent risk of falsely declaring a test failure, and a 5 percent risk of not detecting a failure at 0.10 gallons per hour. The actual test failures could be due to product loss anywhere in the tank system -- in the vessel, lines, pipes, or bungs.

Major Findings - Following are the major findings of this study. The estimates given are subject to sampling error and nonsampling error. The ranges in parentheses following the estimates represent 95 percent confidence limits for the estimates due to sampling error. These national estimates are for the contiguous United States.

1. There are an estimated 796,000 (503,000-1,090,000) individual motor fuel storage tanks in the United States.
    - 158,000 (35-453,000) of these are on farms.

2. The above tanks are located at an estimated 326,000 (296,000-356,000) establishments.

   - 79,000 (58,000-100,000) of these are farms.

   - The estimated mean of number of tanks per establishment is 2.4 (1.6-3.2), overall, which varies from 1.9 for large establishments that are not in a fuel-related business to 3.5 for gasoline stations.

3. Under test conditions, an estimated 35 percent (30-40%) of the non-farm underground motor fuel storage tank systems, including manifolded systems, did not pass the tightness test. This represents an estimated 189,000 (153,000-226,000) tank systems. Using a different test criterion (i.e., the commonly used NFPA 0.05 gallon per hour cutoff) rather than the statistical significance test used above leads to a very similar estimate (33%) of tanks not passing the tightness test with an estimated 44 percent total classified as "uncertifiable" (i.e., 44% = 33% test failures plus 11% untestable tanks and inconclusive test results which are also counted as uncertifiable in most commercial tests). Of the physical tank system tests attempted, 5 percent were untestable with the method used because of unusual system configurations or large interferences.

4. The percentage of fiberglass and steel tank systems that did not pass the tank tightness test were about the same. Steel tanks, which comprise an estimated 89 percent of all underground motor fuel storage tanks, show little increase in the percentage of tank systems not passing the test as they age except for the oldest tanks (over 20 years), for which the percent increases substantially. There is a much smaller sample of fiberglass tanks, so no comparison by material was possible for the tanks aged 20 or more years, but fiberglass and steel tank systems have no significant difference in percent not passing the test at comparable ages. These findings should not necessarily be interpreted as causal effects of age and tank material. Such statistical associations could be caused by other associated variables.

5. This report presents many descriptive statistics on the characteristics of underground tanks and the facilities or establishments at which they are located. For example, based on the national sample estimates:

   - Thirty-one percent of establishments with underground storage of motor fuels also store waste oil underground;
   - Fourteen percent of establishments have one or more abandoned tanks on site;
   - Seventy-eight percent of establishments used clean sand, pearock, or peagravel to backfill around tanks;
   - Twenty-nine percent of establishments are required to have tank operating licenses;
   - Sixty-nine percent of establishments believe they are insured for non-catastrophic leaks;
   - Eleven percent of underground motor fuel tanks are fiberglass;
   - Twenty-one percent of tanks are installed partially or completely below the water table;
   - Twenty-three percent of tanks are in manifolded systems; and
   - The mean age of tanks is 12 years.

6. The statistical analysis did not identify any single explanatory variable (such as age of tank, type of material, or fuel type) that is strongly correlated with tightness test results. Additional multiple regression and logistic models were developed which suggested the possible influence of a few variables, but their ability to predict the test outcome was weak, as described in the appendices of this report. Soil characteristics were not among the variables analyzed because they were not available in the data base during this study. Soil data more recently developed by EPA and General Software Corporation are described in the appendices of this report.

7. There is only limited agreement between inventory analysis methods and tightness test outcomes on a tank-by-tank basis. It is possible that a longer period than 28 days of inventory data might improve the level of agreement. While each of three inventory methods provided roughly similar overall estimates for the percent of tank systems that might leak, there were substantial disagreements among the inventory methods as to which tank systems leak.

   - It is very difficult to obtain accurate and usable inventory data. Owners and operators had trouble following even simple inventory data collection procedures. The 78 percent response rate was achieved only after extensive followup efforts. It is not that inventory control does not work, it is just that the successful execution of it is difficult to achieve.

   - EPA feels that the failure of the inventory analyses as part of the survey was a result of human error and inconsistency and we do not view it as a basic failing of inventory methods.

8. For the tank system tightness tests, EPA initially conducted an extensive evaluation program to test existing methods, then selected one of these, modified it to improve its accuracy, and characterized its field performance. The method used by EPA has stated procedures to identify and correct for potential interference problems which commonly occur in the field and which can otherwise invalidate the test results. These interferences include tank end deflection, temperature effects, water table and vapor pockets. With the modified method, EPA was able to detect a 0.10 gallon/hour leak with 95 percent probability while correctly identifying a tight system with 95 percent probability.

   None of the existing test methods evaluated by EPA could consistently and reliably achieve detection of the 0.05 gallon/hour leak rate specified by the NFPA 329 "Recommended Practices for Underground Leakage of Flammable and Combustible Liquids, 1983." This conclusion is based entirely on the data collected during EPA's evaluation program since supporting data which had been requested from the test companies to document their performance claims were not received.

While some methods can provide reliable results under some specific conditions, most of them do not take definitive steps to deal with the commonly occurring interference problems previously mentioned. EPA believes that in general the field performance of existing test methods could be improved by:

- training field crews to identify interference problems;
- developing stated procedures to deal with interference problems; and
- increasing frequency and duration of data collection.

In any case, it is important that those who must rely on the results from these methods be informed about their performance characteristics. If valid performance data on a method do not exist, they should be generated. If they do exist, they should be made available to those who are potential users.

Simply put, EPA believes that there are problems with existing tank system tightness tests. EPA believes these problems are correctable and for this survey EPA chose a method, modified it to deal with these problems and was able to improve the accuracy over existing methods.

SECTION 1

INTRODUCTION

The National Underground Storage Tank Survey was designed to provide estimates of the number of underground motor fuel storage tanks and the number of establishments with such tanks, the number and percent of tank systems that leak, and characteristics of tanks and tank establishments. Tank and establishment characteristics were analyzed in a search for possible correlations with leak status (whether a tank is leaking) and leak rate. The survey sample was a national probability sample of establishments in the U.S. (except Hawaii and Alaska) that had underground motor fuel storage tanks (not abandoned).

The survey consisted of a series of information-gathering procedures which included an in-person interview, inventory data collection, tank tightness testing, and secondary data abstracting. This report presents national estimates for statistics based on data collected in the interview phase of the survey, analysis of the inventory data collection, and results of the tightness testing phase.

The tank and establishment characteristics data presented in this report were collected through in-person interviews conducted by Westat field interviewers using the "Underground Storage Tank Survey Establishment Operator's Questionnaire" (see Appendix F for a facsimile of this questionnaire). The results reported here are based on interviews conducted during visits to 890 establishments. As a part of the tank tightness test fieldwork (at a subsample of establishments), certain tank and establishment characteristics were also collected by the Midwest Research Institute tank tightness test field crews. This information was checked against interview data and discrepancies resolved by telephone recontact and checking the hard data from both sources. The tank system leak data in this report were collected by on-site tank system and manifolded tank system tests conducted by Midwest Research Institute field crews using a modified PetroTite procedure.

I. DEFINITION OF KEY TERMS

For the purposes of this survey, an establishment is defined as any site or location where underground storage tanks are being used to store and dispense motor fuel for business, commercial, government, and, in a few instances, farm purposes. The term "tank system" refers to an individual underground storage tank vessel plus the lines and equipment that are connected to that vessel. At some establishments, two or more tanks are linked together by piping in "manifolded tank systems." Manifolded tank systems often present special data collection problems. For inventory reconciliation and sometimes for tank tightness testing, it was necessary to collect data at the "manifolded tank system" level rather than for the individual tank systems. For example, when two manifolded tanks have one meter, inventory data must be collected for the manifolded system as a whole in order to compare meter data to stick data. In physical tank tightness tests, tanks in manifolded systems were not isolated for testing when, for example, they were joined by inaccessible lines. In the interview procedure it was possible to collect data (such as age, size, construction material) on an individual tank basis.

Our analytical approach has been to report results at the smallest unit of analysis, whenever possible. Thus, interview-collected characteristics and national estimates of the numbers and types of tank establishments and tanks (in Section 9) are

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reported for individual tank systems rather than for "manifolded tank systems." Similarly, leak status and leak rate analyses will be based on the smallest available unit tested. Thus, for tanks in manifolded systems that were separated and tested individually, leak rate and status will be reported for individual tank systems rather than for the tanks combined into a manifolded tank system leak rate and status. However, for those manifolded tank systems that were not separated for testing, the leak status and rate reported are the manifolded tank system test status and rate. The text for each table defines the unit of analysis used in the table.

II. TYPES OF TANKS COVERED BY THE UNDERGROUND STORAGE TANK SURVEY

The Underground Storage Tank Survey was limited, for practical and regulatory reasons, to underground tanks that store and dispense motor fuel prior to end use by business, commercial and government establishments. **This limitation excludes** tanks used to store materials other than motor fuels such as chemicals, waste-water, hazardous waste, heating oil, and used or waste oil. Also excluded by definition are motor fuel storage tanks that are at private residences, above-ground or partially buried tanks, and all motor fuel tanks at bulk storage facilities that do not dispense fuel to end users. Tanks that are abandoned or empty were also excluded from consideration. **Included** within the scope of the survey are tanks that are owned and operated by private businesses, public and government institutions, military facilities, and farms. The initial step of the data collection effort was to determine, for a random sample of establishments, whether they in fact had an active underground motor fuel storage tank as defined above. If so, the establishment (and its tanks) were considered eligible for the survey, and the main questionnaire was administered.

As a result, the sample includes such establishments as gasoline stations, airports, marinas, rental car agencies, fleets of trucks or company cars, bus companies, fire stations, parks, police stations, and many other types of establishment.

III. LIMITATIONS OF THE DATA PRESENTED IN THIS REPORT

As in any research report of this type, there are limitations in the study's scope and methods which should be understood by all who interpret and use the results of the study. The major limitations are summarized below as caveats which must be kept in mind by the reader.

A. Sample Frame Limitations

Because of practical and economic considerations, the sample was drawn from those establishments most likely to have the types of underground tanks described above (Subsection II). All establishment types and industries were covered except small (less than 20 employees) businesses in non-fuel-related industries. As a result, the study would not have counted any underground motor fuel tanks in small businesses, private homes, and less relevant industry sectors. In other words, it is possible that the number of underground motor fuel tanks in the nation is somewhat greater than our estimate. However, we would expect roughly similar leakage experience in uncovered business establishments, based on the relatively constant percentage of tanks leaking across the different sectors studied.

B. Owner/Operator Responses

The tank and establishment characteristics data presented in this report were collected by Westat interviewers during an in-person interview with establishment owners and operators. The accuracy of these data is limited by the knowledge of the responding owner/operator.

A substantial number of owner/operators responded "don't know" to interview questions about certain tank characteristics such as the age of the tank or the material of construction. Because the information may prove useful in regulatory development, we have included information on the percentage of "don't know" responses when this was substantial.

C. Inventory Data

Reconciliation of inventory records received from respondents was evaluated as a secondary, more economical method of detecting tank system leaks and estimating tank system leak rates. Inventory data were analyzed by Warren Rogers Associates, Inc. (WRA), using proprietary inventory reconciliation analysis software. Alternative methods were also explored. Some limitations to the usefulness of the inventory data are related to the ability of the owner/operator to accurately collect it. Because many tank managers do not normally maintain such inventory records they often produced error-prone data, which could not be analyzed. This occurred frequently in establishments which had fairly inactive tanks (fuel was dispensed only once or twice a week) and when the volume of fuel in a tank was very low. Very accurate measurements were needed for the WRA analysis. A less demanding analytical protocol might have been able to use a higher proportion of the inventory data received.

D. Line, Vessel, and Equipment Leaks

Based on tank test methods used in this study, it was generally not possible to distinguish between leaks occurring in the tank vessel and leaks occurring only in lines or equipment such as fill pipes, manways, vent pipes, distribution lines, joints and bungs. Leak tests of distribution lines in isolation from their tanks were possible for about one-third of the tested tanks found to be leaking. (A distribution line test was always attempted but could not be completed in many cases.) The distribution line leak data are analyzed in Section 8. Elsewhere in this report, no distinction is made between tank vessel leaks and distribution line leaks or other non-vessel leaks. A leak anywhere in the system is reported as a tank system leak. Also, for manifolded systems of more than one tank where the tanks were not separated for testing, the entire system was tested and a reported leak could be in any of the tanks or in any associated line, pipe, fitting, joint, or other equipment.

E. Test Conditions Versus Operational Conditions

The tank tightness test conditions include some circumstances which are not always present during normal tank operations. Specifically, during the test tanks were overfilled (i.e., tanks were filled as were the associated fill pipe and additional testing apparatus to permit measurements) such that the net pressure at the tank bottom was 4 psig. The test procedure compensates for hydrostatic pressure when the water table is above the bottom of the tank by increasing the height of overfill. As a result of the overfilling, tanks that leak only near or at the top of the tank or in lines, pipes, or joints not normally filled with fuel might not always (or might never) be leaking in normal operations if the tank is kept less than full. The impact of increased leak rate because of test pressure is less of a problem than leaks at non-operational locations because the test pressure is small, and test leak rates have been adjusted downward to correct to typical operating pressures. (Section 8 discusses the typical fill levels reported in the interview phase and their effects on leak status statistics, and also describes the leak rate adjustment procedures.)

F. Interpretation and Adjustment of Tank Tightness Test Data

Many factors affect the reliability of tank tightness test data. The most important factor is temperature effect. Because the volume of fuel in a tank varies with temperature change, it was necessary to measure temperature changes directly and adjust results using a correction and smoothing process. These adjustment procedures required careful engineering and statistical review and data editing using engineering judgment to rule out suspect data. Some introduction of error is possible in such engineering judgments, but careful discarding of suspect data increased the overall validity of the findings. (Section 7 describes the data reduction procedures applied to the raw data.)

G. Untestable Tanks and Unreliable Test Data

The primary purpose of the tightness testing phase of the survey was to estimate the number and proportion of leaking tanks and to estimate the leak rates of those tanks. The degree to which the test data fulfill the objectives of the survey is limited by the number of tanks for which responses were obtained. For approximately 10 percent of the tanks selected for testing, the tests were unsuccessful because the tank was untestable or the resulting test data were unreliable. Reasons for untestability included plumbing and piping problems and other installation factors, such as physical constraints on the placing of the test equipment in the tank. Reasons for unreliable tests included trapped vapor pockets in the tank vessel or lines, and unexplained temperature variations. For an additional five percent of the selected tanks, the leak rate could not be measured due to the great size and speed of the leak (although leak status was determined). Generally, leaks at a rate of three or more gallons per hour under test pressure could not be quantified by the test procedure.

IV. Overview of the Report

Chapter 2 presents the major findings from the interview and tank tightness test data as well as operational findings of interest in developing regulations. Chapter 3 describes the quality assurance program, with results given as appropriate in the subsequent chapters. Chapter 4 describes the sample selection and estimation procedures, Chapter 5 gives the field procedures for the questionnaire and inventory data collection, and Chapter 6 describes the tank tightness test data collection. Chapter 7 gives the tank testing data reduction process and quality assurance results, and Chapter 8 describes further statistical analyses applied which resulted in the final determination of whether a tested tank was leaking. The actual data are presented in tabular form in Chapter 9, together with the findings of some analyses designed to search for possible correlations between tank and establishment characteristics and leak status of tanks. Chapter 10 presents the findings on inventory reconciliation techniques.

The Appendices provide further details supporting these discussions.

SECTION 2

CONCLUSIONS

I. ACCURACY OF ESTIMATES

A. Accuracy and Sampling Error

The major findings of this survey are the national estimates made from the data. These are presented in tabular form, along with statements based on the data. The numbers are statistically unbiased estimates based on a national probability sample, and represent a sample estimate of the result that would be obtained from a census of the target universe in which standard questionnaire data collection and physical tank testing was conducted for all tanks and establishments in the target universe. The size of the difference between sample results and results from such a hypothetical census are measured by sample variances estimated from the survey data. Thus, the accuracy of the figures can be objectively assessed as far as sampling error is concerned. Non-sampling error is discussed below.

Estimates are given together with 95 percent confidence limits in parentheses. These confidence limits are based on the sampling variances estimated from the survey data. (The estimation procedures are discussed in Section 4 and Appendix A.) The limits can be expressed as the following statements. For the first entry in Table 2-1 for the total of all establishments, which is 326 (296-356) thousand, one would say, "It is estimated with 95 percent confidence that the number of establishments with underground motor fuel storage tanks is between 296,000 and 356,000 establishments, with a point estimate of 326,000

Table 2-1. Estimates, by type of establishment, of the number of underground motor fuel storage tanks and the number of establishments with underground motor fuel storage tanks in the continental United States (95% confidence bounds in parentheses)

Type of establishment	Number of establishments with tanks (1,000's)	Number of tanks (1,000's)	Number of tanks per establishment	
			Mean	Median
Government and military	45 (29-62)	98 (69-128)	2.2 (1.8-2.5)	2
Gas stations owned by major petroleum companies	33 (26-41)	118 (87-148)	3.6 (3.3-3.8)	3
Gas stations owned by other companies	58 (50-67)	204 (174-233)	3.5 (3.2-3.8)	3
Other fuel-related establishments	36 (30-43)	77 (64-90)	2.1 (1.8-2.4)	2
Large non fuel-related estabments (with ≥ 20 employees)	74 (55-93)	142 (97-187)	1.9 (1.6-2.2)	2
Total for business and government establistments	247 (220-275)	638 (584-692)	2.6 (2.4-2.8)	3
Total for farms	79 (58-100)	158 (<453)	2.0 (<5.0)	1
TOTAL	326 (296-356)	796 (503-1,090)	2.4 (1.6-3.2)	3

establishments." This means that there is only a 5 percent chance that the actual value falls outside of this range. When an upper limit is given, as in the estimate of number of eligible tanks on farms in Table 2-1, where the entry is 158 (less than 453) thousand, this indicates that the lower bound of the confidence interval is a small number. The statement for this estimate would be, "It is estimated with 95 percent confidence that the number of underground motor fuel storage tanks on farms is less than 453,000, with a point estimate of 158,000." This means that there is only a 5 percent chance that the actual value is greater than the upper limit.

B. Non-Sampling Error

As in any data collection effort, non-sampling error is also present in these data. This type of error is not quantified in the confidence intervals but has been explored and reported on in several places in the report. Potential non-sampling errors include deficiencies in the sampling frame, respondent errors, physical test errors, and inventory recording and analysis errors. In this survey, one potential non-sampling error investigated in depth comes from the physical tank testing. Several parts of the report discuss the test method. Section 1, in particular, has reviewed the limitations in the interpretation of the results which stem from the testing method chosen. First, a leak detected by the test may represent a hole anywhere in the system of tank vessel and associated lines, pipes and fittings, or indeed a loose connection within this system. Second, it cannot be definitively determined from the data where the detected hole or loose connection is or when or whether a leak occurs under operating conditions. Section 8 offers two relevant pieces of information: Tanks do tend to be nearly or completely filled at delivery (so that holes or loose fittings at or near the top of the tank would have occasion to leak in practice); and when distribution line tests were possible, the measured rate of the line leak accounted for very little of the measured tank system leak (so that detected leaks do not appear to be in the distribution lines). As is described in Sections 6 and 7, factors which could lead to difficulties with the physical testing such as uneven product temperature, change in temperature, erratic measurements, vapor pockets, and tank end deformation due to test pressure have been carefully accounted for in the the test procedure and subsequent data reduction process.

II. NATIONAL ESTIMATES

The major findings are given in Tables 2-1 through 2-3.

- Number of Establishments with Tanks -- Table 2-1 presents survey estimates of the number of underground motor fuel storage tanks and the number of establishments with such tanks, as well as the mean and median number of tanks per establishment, by type of establishment. The national estimate for the number of tanks is 796,000 with 95 percent confidence bounds of 503,000 to 1,090,000. This total includes farms. Since so few farms surveyed actually had underground motor fuel storage tanks (20 out of a sample of 600), further national estimates including farms could not be accurately made and therefore are not presented. The national estimate of business and government tank establishments is 247,000 (220,000-275,000) and the number of non-farm tanks is estimated to be 638,000 (584,000-692,000).

- Percentage of Tank Systems Judged to be Leaking under Test Conditions -- Table 2-2 shows the estimated number and percent of business and government tanks judged to be leaking under test conditions by establishment type, based on the physical tightness test results. Based on tested tank systems which yielded valid test results, an estimated 35 percent of tank systems are judged to be leaking under test conditions, with 95 percent confidence bounds of 30 to 40 percent.

Table 2-2. Estimated number and percent of tank systems[1,2] judged to be leaking under test conditions by establishment type (95% confidence bounds in parentheses)

Establishment type	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking (of tanks with conclusive test results)[3]
Government and military	29 (5-54)	36 (16-55)
Gas stations owned by major petroleum companies	25 (11-38)	32 (19-45)
Gas stations owned by other companies	56 (40-71)	30 (22-37)
Other fuel-related establishments	35 (25-45)	57 (43-71)
Large nonfuel-related establishments	45 (19-71)	33 (18-47)
Total	189 (153-226)	35 (30-40)

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[1] In this table, tank test results are reported for individual tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded systems are included in the table.

[2] Does not include farm tanks.

[3] Excludes tank systems for which test results were inconclusive. (Therefore the estimated number in this table, when divided by the estimated totals in Table 2-1, will not give the percentages shown here.)

Table 2-3. Estimates by establishment type of mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions (95% confidence bounds on the means in parentheses)

Establishment type	Mean adjusted leak rate (gph)[5]	Median adjusted[3] leak rate[4] (gph)
Government and military	0.26 (0.06-0.47)	0.27
Gas stations owned by major petroleum companies	0.42 (0.18-0.68)	0.29
Gas stations owned by other companies	0.24 (0.13-0.34)	0.28
Other fuel-related establishments	0.45 (0.20-0.71)	0.32
Large nonfuel-related establishments	0.25 (0.14-0.36)	0.14
Total	0.32 (0.24-0.39)	0.25

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[1] In this table, tank test results are reported for individual tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. Results for manifolded systems are included in the table.

[2] Does not include farm tanks.

[3] Leak rates of leaking tank systems were adjusted to operating pressure.

[4] Calculation of median adjusted leak rate includes tanks judged to have unquantifiably large leaks.

[5] Calculation of mean adjusted leak rate includes only those tank systems judged to be leaking which had quantifiable leak rates.

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- Percentage of Tank Systems Leaking Under Operating Conditions -- Under operating conditions, the percentage of tank systems that are leaking might be somewhat less. This could vary from 18 percent at a random point in time to 29 percent at the time of product delivery the way tanks are normally filled, and to 35 percent at the time tanks are filled if they are filled to capacity. (See further discussion in III below.)

- Leak Rates -- Table 2-3 presents the mean and median leak rate for tank systems judged to be leaking under test conditions by establishment type for business and government tanks. These leak rates have been adjusted to typical operating conditions (see Section 8). The mean leak rate for all business and government tanks is 0.32 gallons per hour with 95 percent confidence bounds of 0.24 to 0.39 gallons per hour. This is based on tank systems judged to be leaking which had quantifiable leak rates. Some tanks showed leaks too large to quantify so the estimated mean leak rate is conservative.

- Incidence of Underground Motor Fuel Tanks Among Various Types of Establishments -- The screening effort revealed a low incidence of underground motor fuel tanks for certain types of establishment. Twenty-four percent (19-28%) of fuel-related establishments (other than gas stations) have underground motor-fuel storage tanks. Thirteen percent (9-16%) of large establishments not in fuel-related establishments have eligible tanks. Three percent (2-4%) of farms have eligible tanks. **However, as is seen in Tables 2-1 and 2-2, a substantial proportion of the tank and tank establishment universe is found in these types of establishments** even though many such establishments do not have underground motor fuel storage tanks.

III. LEAK STATUS UNDER OPERATING CONDITIONS

Certain features of the tank testing method are different from typical operating conditions, especially the overfilling of the tank during the test.

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It is certainly reasonable to ask whether some of the leaks detected under test conditions might have been due to holes near the top of the tank or in lines, pipes and fittings above normal fill levels. Data from the survey reveal that it is common practice to fill tanks to 100 percent capacity when product is delivered. In fact, 100 percent was the modal value for this variable, and the median of the reported average fill level was 83 percent of capacity. Thus, the data suggest that even holes near the top of the tanks would be subject to leaking, at least just after product delivery.

On the other hand, the average tank fill level just prior to delivery had a median value of about 20 percent of tank capacity. Therefore, as a rough approximation, a typical operating level might be midway between the high and low point, or 52 percent of capacity. If one were to further assume that holes were evenly distributed between the top and bottom of the tank, then an estimated 52 percent x 35 percent = 18 percent of the tank systems would be leaking on the average at any point in time under typical fill level conditions.[1] Furthermore, using average percent filled after delivery may be a conservative estimate of operational fill levels. When asked about the maximum gallons ever stored, most respondents reported 100 percent, and only one-quarter were below 92 percent full.

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[1] This is a rough approximation which could be refined by calculating highest and lowest fill levels for each tank separately, and then computing the median and mean fill levels as fuel is withdrawn. Fuel withdrawal rate could be assumed as uniform over time or simulated from inventory data. Finally, refinements could be made to account for the fact that the assumption of uniform leak distribution over the surface of the tank is not identical to uniform leak distribution over volume. However, since actual leak distribution is unknown, such refinements do not seem warranted at present.

In summary, if we are willing to assume that holes are uniformly distributed around the tank circumference (we have no data to verify this assumption), we could calculate that:

- Approximately 35 percent of the tank systems would be leaking if they were filled to capacity;
- If all tanks are ever filled to capacity during the year, then an estimated 35 percent of the tank systems in the country are leaking at one time or another during a year;
- Approximately 29 percent (.35 x .83) of tank systems are leaking just after the time of product delivery the way tanks are normally filled; and
- Approximately 18 percent (.35 x .52) of the tanks are leaking at a random point in time.

Based on a limited set of 43 leaking tank systems where it was possible to test the leak status of distribution lines separately, it was found that the distribution line leak rate makes up a very small portion of total tank system leak rate. Distribution line leaks made up a small portion of the total system leak rate.

IV. ESTABLISHMENT CHARACTERISTICS

Descriptive statistics for establishments include:

- Thirty-one percent (27-35%) of establishments with underground storage of motor fuels also store waste oil underground.
- Fourteen percent (11-17%) of establishments with in-use underground motor fuel storage tanks also have one or more abandoned underground storage tanks on site.

- Seventy-eight percent (73-83%) of establishments used clean sand, pearock or peagravel to backfill around tanks (one-quarter of owner/operators did not know the backfill material).

- Twenty-nine percent (21-37%) of establishments are required to have tank operating licenses (whether this was required was not known by 16% of owner/operators).

- Sixty-nine percent (64-75%) of establishments believe they are insured for non-catastrophic leaks (22% of owner/operators did not know the answer to this question).

V. TANK CHARACTERISTICS

Other descriptive findings include:

- The mean age of eligible business and government tanks is 12 years (11-13 years). The mean capacity is 5,405 gallons (5,026-5,783 gallons).

- Forty-two percent (37-46%) of business and government tanks store unleaded gasoline, 33 percent (30-36%) store leaded gasoline and 21 percent (17-26%) store diesel fuel. The remaining tanks store aviation fuel, jet fuel, gasohol or other products used as motor fuel.

- Eleven percent (7-15%) of tanks with known construction material are fiberglass.

- Twenty-one percent (17-25%) of tanks with known positions in relation to the water table are partly or completely below the water table (tank owner/operators do not know this status for one-third of tanks).

- Twenty-three percent (18-27%) of tanks are part of a manifolded system.

- Five percent (3-6%) of tanks for which the owner/operators knew whether cathodic protection was installed do have such protection (tank owner/operators did not know the answer to this question for 13% of tanks; it is unlikely that such a system would work well if the operator were unaware of its existence).

- Twenty percent (14-26%) of tanks were installed by the owner/operators themselves (this is among the 54% of owner/operators who knew the identity of the installer).

VI. TANK CHARACTERISTICS ASSOCIATED WITH LEAKS

Statistics describing tank systems judged to be leaking under test conditions include:

- Fifty-seven percent (46-67%) of tank systems storing diesel fuel are judged to be leaking under test conditions, while 18 percent (9-26%) of tank systems storing leaded gasoline are judged to be leaking under test conditions. Thirty percent (26%-41%) of tank systems storing unleaded gasoline are judged to be leaking under test conditions. These differences in percent leaking by fuel type could be due to some other variable associated with fuel type. No conclusion should be drawn about the effect of fuel type without further research.

- Fifty-four percent (39-68%) of tanks in manifolded systems are judged to be leaking under test conditions, while 31 percent (26-36%) of single tank systems are judged to be leaking.

- Thirty-one percent (15-48%) of fiberglass tank systems (i.e., tank systems in which the tank is made of fiberglass although lines, pipes, and fittings may not be) are judged to be leaking under test conditions. This figure is quite similar to the proportions of steel tank systems judged to be leaking, whether bare (uncoated) with 32 percent (14-49%), or coated, with 38 percent (30-46%).

- Steel tanks, which comprise 89 percent of all underground motor fuel storage tanks, show little increase in percentage of tank systems judged to be leaking as they age except for the oldest tanks (over 20 years of age) for which the percent judged to be leaking increases substantially to 58 percent (29-77%). No fiberglass tanks over 20 years old were found in our sample, so percent judged to be leaking cannot be compared across material type for this age category. Fiberglass and steel tank systems show similar proportions judged to be leaking for the younger age categories. For example, among tanks less than five years old, 38 percent (11-65%) of steel tank systems are judged to be leaking and 26 percent (<77%) of fiberglass tanks are judged to be leaking. The broad confidence bounds are due to the small sample sizes (46 and 7 tank systems tested, respectively). Furthermore, for tanks between five and 20 years old, the percent of tank systems judged to be leaking under test conditions are similar for fiberglass tank systems and steel tank systems.

The statistical analysis did not identify any single explanatory variable (such as age of tank, type of material, or fuel type) that is strongly correlated with either leak status or tank system leak rate. Additional multiple regression and logistic models were developed which suggested the possible influence of a few variables, but their ability to predict leak status or leak rate was weak, as described in Section 9, Subsection VI, and Appendix I. Soil characteristics were not among the variables analyzed because they were not available in the data base during this study. Soil data more recently developed by EPA and General Software Corporation are described in Appendix H.

VII. OPERATIONAL FINDINGS

A. Tightness Test Method Development

There were a number of possible tank system testing methods commercially available at the time of the survey. OTS modified an existing method in order to improve the reliability for the survey (see MRI draft report, November 7, 1985 for OTS, "Development of a Tank Test Method for a National Survey of Underground Storage Tanks," which is summarized in Appendix C).

B. Establishment Manager Cooperation and Inventory Participation in the Field Interview Phase

Participation in the field interview phase of the survey was nearly 100 percent overall. As indicated in Table 2-4, 99.3 percent of all eligible respondents completed interviews. The highest response rate among the sample segments was among the large establishments where 100 percent of the eligible establishments provided interview data.

It is very difficult to obtain accurate and usable inventory data. Owners and operators had trouble following even simple inventory data collection procedures. The 78 percent response rate was achieved only after extensive followup efforts. About 90 percent of these respondents required technical assistance to collect the inventory data. This contrasts with the 60 percent of owner/operators who responded "yes" to the questionnaire item, "Do you reconcile your stick inventory with your book inventory?" The lowest inventory data response rate was from the farm sample, where only 35 percent of all eligible farms provided inventory. Of all eligible respondents, 16 percent have not yet provided any inventory. Problems that establishment operators encountered in keeping inventory records are described in detail in Section 5.

C. Tightness Test Cooperation

The physical tank testing response (cooperation) rate was 95 percent and complete, usable results were obtained from 85 percent of the subsample of tank systems and manifolded tank systems. Test results were judged reliable in about 89 percent of the tank systems and manifolded tank systems where tests were

Table 2-4. Field interviewing and inventory response rates

	Farms	Large establishments	Fuel-related establishments*	Total
A. Number of eligible establishments	20	76	800	896
B. Response rate (percent of eligible respondents who completed interview)	95%	100%	99.4%	99.3%
C. Refusal rate (percent of eligible respondents who refused interview)	5%	0%	0.6%	0.7%
D. Inventory response rate (percent of eligible respondents who returned inventory)	35%	79%	78.8%	77.8%
E. Inventory refusal rate (percent of eligible respondents who refused to record inventory)	30%	1.3%	1%	1.7%
F. Percent of establishments delinquent in returning inventory	20%	11.8%	16.4%	16.1%
G. Percent of establishments for which inventory measurements are impossible	15%	7.9%	3.8%	4.4%

*including government and military establishment attempted. Approximately 5 percent of the tank systems and manifolded tank systems where tests were attempted were not testable for technical reasons which are discussed in more detail in Section 6. Table 2-5 presents the tightness test completion rates for the survey.

The testing methods used in the survey required that the tank be out of service for one day and be filled to capacity at the start of the test. Difficulties in arranging for a fuel delivery, scheduling an acceptable test time, or physical problems with the tank and with its associated plumbing add significantly to both the time required and the cost of physical testing. Severe operational difficulties requiring excavation were encountered in about 14 percent of the tanks. More details on these problems appear in Section 6.

Table 2-5. Tank testing completion statistics

	Single tank or manifolded tank systems	Total number of individual tanks at these systems
A. Number selected for tightness testing	484	561
1. Percent of out of scope of survey[1]	0.8%	0.7%
2. Percent at sites refusing to participate	5.0%	4.8%
B. Number of tests attempted	456	530
1. Percent untestable for technical reasons	5%	5%
2. Percent for which test results were unreliable or inclusive	6%	5%
3. Percent with reliable, conclusive test results	89%	90%
	100%	100%
C. Response rate for estimates of the percentage of tank systems that are leaking[2]	85%	86%

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[1] Became out of scope after the interview phase (for example, went out of business).

[2] These response rates are the number of reliable test results out of the eligible cases selected. From the figures presented above, they can be calculated as (0.89 x 456)/((1.0 - 0.008) x 484) = 0.85 and (0.90 x 530)/((1.0 - 0.007) x 561) = 0.86.

SECTION 3

QUALITY ASSURANCE APPROACH

Rigorous quality assurance (QA) procedures were applied to all stages of the survey to ensure that the data are of known quality. These procedures are detailed in two QA Plans[1]; one covering the overall survey and one dealing specifically with tank testing. This section provides a brief overview.

In addition to the procedures outlined here and detailed in the QA plans, the survey was audited by EPA QA personnel. This involved site visits, productivity and response rate monitoring, and QA audits and reviews of home office processing procedures.

Data quality is assessed by its representativeness, completeness, accuracy, precision and comparability. The sample of establishments and their underground storage tanks must be representative of the population of establishments and tanks about which inferences are to be made. A complete, or almost complete, set of data must be collected; otherwise, its representativeness, accuracy and precision will be compromised. Accuracy (lack of bias) and precision must be sufficiently high so that confidence can be placed in the numerical value of the results. The methods employed must be well documented and allow results. The methods employed must be well documented and allow comparison of the results with other relevant studies. The succeeding pages outline procedures used at each stage of the study to assess and maximize data quality. Quantitative measures of data quality are presented in the appropriate sections throughout the report.

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[1] LUST Quality Control Procedures, National Survey of Underground Storage Tanks, Quality Assurance Plan, Westat, July 12, 1985; and National Survey of Underground Storage Tanks Draft Quality Assurance Program Plan for the Office of Toxic Substances, Midwest Research Institute, June 7, 1985.

I. DEVELOPMENT OF SAMPLING FRAME AND SAMPLE SELECTION

The objective of the survey is to provide national and regional estimates of the number and proportion of underground motor fuel storage tanks that leak, and to investigate characteristics of leaking tanks. To achieve this objective, the information collected must be representative of storage tanks throughout the country. Representativeness was ensured by careful development of the sampling frames and methods of sample selection.

The entire contiguous United States was divided into Primary Sampling Units (PSUs) consisting of counties or groups of counties with a minimum number of gas stations and other fuel-related business establishments. A probability sample of PSUs was drawn, and sample summary statistics were compared with summary statistics calculated from the entire frame to check that the random selection procedure had been applied correctly.

Section 4 and Appendix A detail the construction of frames and sample selection for the fuel establishment, large establishment and farm samples. In each case, checks were made between frame and sample summary statistics.

II. PREPARATION OF QUESTIONNAIRES AND INTERVIEWS

Versions of the questionnaire and inventory recording forms were pretested, both informally and in extensive formal pretests. The questionnaire, together with an instruction booklet, was sent to the respondent prior to the interview to allow the respondent to look up information not immediately available and thereby improve the quality (accuracy and completeness) of the response. Questionnaire packages were sent by certified mail to provide a record of receipt.

Interviewers were carefully selected and underwent a five-day training session that included instruction at both Westat and MRI in Kansas City. They were provided with a detailed interviewer's manual that explained project and administrative procedures, and provided item-by-item specifications for the questionnaire.

III. INTERVIEWING

One or more interviewers were assigned to each PSU. They received call records and labels for each of their assigned cases, and were to complete a questionnaire for each eligible case. All survey materials for completed work were sent to the home office weekly. Call records for ineligible as well as eligible cases had to be returned with the reason for ineligibility clearly marked on the call record. Interviewers were required to make weekly progress reports by telephone.

In addition to questionnaire administration, interviewers were responsible for conducting a meter accuracy test, reviewing inventory procedures with the respondent, and collecting other information on the location and nature of the establishment. The measured meter errors were used to adjust the meter sales figures to give actual quantities dispensed each day. This, in turn, reduces the incidence of false-positive results from inventory reconciliation analyses when quantity dispensed is compared to stick readings. Review of inventory procedures was aimed at improving the respondent's ability to understand and correctly complete the inventory recording forms.

Interviews from the field were checked for completeness, given a final interview status code, and logged into an automated receipt control system. Refusals to comply with this mandatory survey were reported directly to EPA's Office of Enforcement and Compliance Monitoring. Most refusals eventually complied, and the overall response rate was 99.3 percent. Approximately 78 percent of the eligible establishments furnished complete or partial inventory data. Difficulties in gathering inventory data are discussed in Section 5.

Initially, replacements for ineligible (i.e., out of scope because no below-ground tanks, no motor fuel, etc.) fuel establishments were selected after their ineligible status had been determined. An unexpectedly high ineligibility rate of about 50 percent made this procedure impractical. Subsequently, the lists were oversampled, and the interviewers screened for eligibility in the field. This made replacement errors less likely.

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IV. DATA TRACKING

An automated receipt control system was developed to maintain a record of the status of each data type for each establishment. The data types and activities logged into the system include:

- Certified mail cards - date received;
- No tank certifications - date received;
- Interview status - Complete, Partially Complete, Ineligible, etc., with appropriate dates;
- Contact name, mailing address and telephone number;
- Prompt call status - date of call to prompt for inventory records;
- Inventory status - Complete, Partially Complete, Refused, etc.;
- Tightness test flag - establishments selected for tightness testing;
- Tightness test status - Complete, Partially Complete, Refused, etc.;
- Map status - Availability of soil and hydrogeologic data; and
- Final status - Computed from the above status fields.

The system enabled the survey to be monitored on a continuous basis by providing document control and producing various lists and reports. Discrepancy reports indicating missing data types, such as missing inventories or missing "No

Tank" certification, provided measures of the completeness of the survey.

V. SELECTION OF ESTABLISHMENTS FOR TIGHTNESS TESTING

The frame was developed from the information in the receipt control system and checked against manual records before drawing the sample. Weighted and unweighted summaries of the sample were calculated to check that the sample of 198 establishments was drawn correctly from the 876 eligible business and government establishments. All 20 farms were scheduled for testing.

Notification packages were sent to each selected establishment with a request for a return receipt. Four to seven days after the mailing, each respondent was called to verify that the package had arrived and that the testing procedure was understood.

VI. TIGHTNESS TESTING

A. Training Tightness Teams

To assure that testing conducted by the several tank testing crews would produce accurate and reliable results, a formal training program was conducted prior to the beginning of the testing program. All of the crew members participating in the training were employees of O.H. Materials, Inc. or Double-Check, Inc. and had been trained and certified by Heath Consultants (the manufacturer of the testing equipment) prior to the training for the national survey. The two main objectives of the training were to assure that all crews would follow the same test procedures, and to provide advanced tank testing training.

The MRI field data analysts who accompanied each tank testing crew received a four day training session that covered procedures for collecting data, preparation of site diagrams, computer operations, and data transmission. The analyst's training sessions included hands-on practice experiences in data entry, data transmission and recordkeeping.

It was necessary to add six additional test teams at approximately halfway through the testing program. The test crews were subcontracted through Protanic, Inc, and were selected based on their past performance records, and years of experience. The added crews were trained in the testing protocols by on-site trainers or by sessions held via telephone, and the test crews were teamed with experienced MRI data analysts who monitored the testing procedures. All data collected by the added test teams received extra verification review by Protanic and MRI staff prior to entering the data in the analysis files.

B. Instrument Calibration

The Petro-Tite equipment used to collect the leak rate data includes a thermistor in a probe that is inserted into the fuel tank to monitor fuel temperature and a thermal sensor box which provides an absolute temperature measurement within three degrees

Fahrenheit. The electronic circuit in the thermal sensor box was checked each time the equipment was set up (on site) to assure that the circuit detected a simulated temperature change to within approximately 0.003 degrees Fahrenheit, before the equipment was used in the test.

Thermistors, glass thermometers and barometers used to collect ancillary environmental information such as air temperature, barometric pressure, and surface and subsurface temperature were calibrated at MRI prior to field use, and the calibration data were entered as a part of the project file.

C. Field Inspections

Site visits to tank test operations were conducted by the MRI project leader, the MRI quality assurance coordinator, the field coordinator, and EPA staff. The purposes of the site visits were to evaluate the test protocols, and to assess the performance of the field crews.

D. Data Management and Analysis

A computerized receipt control file was used to track the test data. As the data were processed and reported, that stages of the process were entered into the receipt control file. Weekly reports were printed for project management and reporting.

The tank test data were entered into a portable computer in the field, using a thoroughly tested data entry program. These data files were transmitted to MRI by telephone, where they were stored on disks. The hard copy of the data on the original Petro-Tite sheets, the field copies of the disk files, and the data collected on ambient conditions was sent to MRI on a weekly basis. The field disk files were compared to the transmitted disk files using a computer utility program, in order to detect any transmission errors. All of the data elements to be used in subsequent leak analyses were printed out and hand checked against hard copy.

The data file for each test was hand checked for measurement problems and outliers, which were eliminated prior to the analysis of the file to determine test status and leak rate. Each tank test analysis was checked individually to ensure that the formulas for calculating the leak rate and standard error were correct. Leak rate, test status, and environmental data were abstracted from hard copy and computer files, and coded, keyed, key-verified, and edited prior to being merged with the questionnaire analysis file.

E. The Retest Program and Results

Three types of retesting were carried out to investigate different sources of variation in the test results. Back-to-back retests (on the same day and by the same crew) were conducted to investigate the stability of test results over time. A leak simulation retest was used to check the accuracy of the test in a situation with a constant leak of known rate. "Complete retests" were independent tank tests usually conducted on different days with different crews from the original test, and involving rescheduling the test and refilling the tank.

A detailed analysis and discussion of the retest data is reported in Section 7 and Appendix D of this report.

VII. DATA HANDLING AND MANAGEMENT

Questionnaires were batched in groups of ten and tracked through the entire survey processing operation. Rules for coding and editing were published in a Coding Manual that was updated periodically to include new codes. Coding problems were referred to a supervisor for resolution. Inventory records were reviewed prior to coding so that missing or incorrect information could be recovered or corrected by a phone call to the respondent as soon after receipt as possible. Approximately 90 percent of respondents received prompt or data retrieval calls in an effort to obtain complete and accurate data on both the questionnaires and inventory records. All coded questionnaires were verified by the coding verifier.

All data were key-punched and then key-verified by a second operator and transferred by telephone link to EPA's NCC computer facility at Research Triangle Park in North Carolina. The data were machine edited to check that each data element is in range, that skip patterns were correctly followed, and that answers to related questions are consistent. Errors were corrected and the edit program rerun until no more problems were found. Frequency distributions and various tables were generated to check on data quality. These allowed outliers to be identified and checked to ensure that they are "true" values.

Careful coding and data entry procedures ensure that the final data files accurately represent the information collected by the survey.

VIII. DATA ANALYSIS

National estimates of number of establishments with tanks, number of tanks, percentage of leaking tanks and leak rates were obtained using the methods described in succeeding sections. Where appropriate, the estimates are accompanied by confidence bounds or standard errors to indicate precision. Confidence bounds are narrowest (i.e., the estimates are most precise) for estimates based on data from the entire survey. Estimates based on subsets of the data (e.g., data from individual regions or for tanks of a particular age) have broader confidence intervals.

SECTION 4

SAMPLE DESIGN, ESTIMATION OF SAMPLE WEIGHTS AND VARIANCES

The national probability sample for the Underground Storage Tank survey was drawn in a three-stage sample design that involved sampling establishments from establishment frame lists within 34 survey sites which had been sampled to represent six survey regions. Data were collected from the sampled establishments using several data collection techniques. All sampled establishments were first screened to determine survey eligibility, that is, whether they had an underground motor fuel storage tank. At eligible establishments, the owner or operator of the tank was interviewed in person and instructed in the completion of 30-day inventory records. A sub-sample of the eligible establishments was selected for physical tank tightness testing.

This section reviews the target universe of the survey and then describes the three stages of sampling: Primary Sampling Units (PSUs) or survey sites; establishments for questionnaire and inventory data collection; and the sub-sample of eligible establishments for physical tightness tests. In brief, the sample consisted of 34 PSUs in which 2,218 establishments were sampled. Of these, 896 establishments were eligible for the survey, (i.e., had underground motor fuel storage tanks that were not abandoned) and 890 cooperated with the interview phase. Two hundred eighteen were selected for physical tank testing, which was accomplished at 202 establishments. The section concludes by describing the methods used to calculate the final weights used in making national estimates from the survey and to estimate the sampling error of those estimates. Appendix A gives more details on these subjects, and Appendix G gives a detailed account of the farm sample.

I. SCOPE OF THE SURVEY

The scope of the Underground Storage Tank survey was limited, for practical and regulatory reasons, to underground tanks used to store and dispense motor fuel for business, commercial and government use. This limitation excludes materials other than motor fuels that may be stored in underground storage tanks, such as chemicals, waste water, hazardous waste, heating oil, and used or waste oil. Also excluded by definition are motor fuel storage tanks that are at private residences, above-ground or partially buried tanks, and all motor fuel tanks at bulk storage facilities that do not dispense fuel to end-users. Tanks that are abandoned or empty were also excluded from consideration. Included within the scope of the survey are tanks that are owned and operated by private businesses, public and government institutions, military facilities, and farms.

As a result, our sample includes such establishments as gasoline stations, airports, marinas, rental car agencies, fleets of trucks or company cars, bus companies, and many other establishments. For practical reasons for list building and screening costs, small establishments (with fewer than 20 employees) in industries not judged to be fuel-related were not included in the survey. Table 4-1 is a list of the industries that were judged to be fuel-related. For these industries all establishments were included in the listing process.

Table 4-1. Selected SIC codes for fuel tank establishments frame

SIC code	Description
4010	Railroads, switching and terminal companies
4110+	Local and suburban passenger transportation companies (includes airport transportation, ambulance and limousine services)
4121+	Taxicab companies
4131+	Intercity highway transportation services
4140+	Passenger transportation charter services (includes bus charter, rentals and tours)
4151	School bus companies
4170	Passenger transportation terminal and service facilities
4210+	Trucking companies
4231+	Motor freight terminals
4469A	Marinas
4511	Air transportation, certificated carriers
4521+	Aircraft charter, rental and leasing -- non-certificated carriers
4582A	Airports
4582B+	Aircraft maintenance services
4583	Airport terminal services
5511+	Auto and truck dealers (new and used)
5521+	Used car dealers
5541+	Gasoline service stations
7512+	Passenger car rental and leasing agencies
7513+	Truck rental and leasing agencies
7519+	Utility and house trailer rental agencies
7992+	Public golf courses
7997B+	Golf and country clubs

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II. SAMPLE DESIGN AND SITE SELECTION

A. Sample Design

The contiguous U.S. (forty-eight states plus the District of Columbia) was divided into six survey regions based on broad soil and climatic characteristics. Table 4-2 lists the states which comprise each region. Six Primary Sampling Units (PSUs) were drawn from each region, except for the Mountain region, where four were drawn. The PSUs consist of counties or groups of counties with a minimum count of gas stations and the fuel-related establishments (see Table 4-1). They were sampled within the survey regions on the basis of probability proportional to this count.

Once the 34 survey sites (consisting of 76 counties) were drawn, establishment lists for sampling were constructed for each county. In order to construct the lists, the target universe was divided into three sectors:

1. Fuel-related establishments -- Establishments which by the nature of their business are likely to have underground motor fuel storage tanks. The industries in this category are listed in Table 4-1 and include gas stations, trucking companies, airports, marinas, and others. Government and military establishments with underground motor fuel storage tanks were also part of this sector.
2. Large establishments (20 or more employees) in other industries -- Although the nature of their business would not suggest the presence of underground motor fuel storage tanks; by virtue of their size, these large establishments may have such tanks.
3. Farms were listed and sampled separately -- (See Appendix G for detailed discussion of the farm sample.)

Table 4-2. Six regions for the National Survey of Underground Fuel Storage Tanks

1 -- Northeast

- Maine
- New Hampshire
- Vermont
- Connecticut
- Massachusetts
- Rhode Island
- New York
- New Jersey
- Pensylvania
- Maryland
- Delaware
- Virginia
- West Virginia
- Washington, D. C.

2 -- Southeast

- Kentucky
- Tennessee
- Arkansas
- Louisiana
- Mississippi
- Alabama
- Georgia
- North Carolina
- South Carolina
- Florida

3 -- Midwest

- Wisconsin
- Minnesota
- Iowa
- Missouri
- Illinois
- Indiana
- Ohio
- Michigan

4 -- Central

- North Dakota
- South Dakota
- Nebraska
- Kansas
- Oklahoma
- Texas

5 -- Mountain

- Montana
- Wyoming
- Idaho
- Nevada
- Utah
- Colorado
- Arizona
- New Mexico

6 -- Pacific

- Washington
- Oregon
- California

Separate samples were drawn from the three frames thus established, since they were expected to yield widely varying eligibility rates.

The fuel establishment sample was drawn by region, with equal probability of selection within each region. To reach the target of 800 survey-eligible establishments in this sector, 1,618 establishments were sampled for screening. The large establishment and farm samples were drawn on an equal probability basis nationwide. Six hundred establishments were drawn from each of these frames and the survey-eligible establishments kept.

After the eligible establishments were determined, a sub-sample was drawn for tank tightness testing. All eligible farms were selected for this testing since so few (20) farms were eligible. For the fuel-related and large establishments, the two samples were combined and an equal probability sample drawn from each region. All tanks at sub-sampled establishments were to be tested.

B. PSU (Site) Selection

Once the six survey regions were defined (Table 4-2), a master list of PSUs was developed. For each of the 3,111 counties in the contiguous U.S., several counts were developed. The 1981 County Business Patterns (CBP) data base supplied figures for the number of gas stations, other fuel-related establishments, and establishments in other industries with 20 or more employees. A report prepared by Versar for the EPA (Leaking Underground Storage Tanks Containing Engine Fuels, draft, March 1984) supplied estimates for the number of gas stations on a state-wide basis, based on figures from Petroleum Marketing News (PMN). These counts included all retail outlets for branded gasoline, i.e., convenience stores and other outlets as well as gas stations. The CBP county totals for gas stations were adjusted upwards to sum to the PMN totals. These adjusted counts were added to the CBP other fuel-related establishment totals to get a fuel establishment count for each county. Minimum PSU counts were established by region (so that a sampled PSU would be sure to have enough establishments to list and sample). Counties with fewer fuel establishments than these minima were grouped together to form multi-county PSUs. The 3,111 counties yielded 1,362 PSUs.

Within each survey region the PSUs were sorted by urban versus rural, then by state and finally by PSU measure of size (count of fuel establishments). Six PSUs were selected from each region (four in Region 5 -- Mountain) with probability proportional to measure of size. The resulting 34 sampled PSUs are made up of 76 counties. Twenty-three PSUs are urban and eleven rural, and together they form a probability sample representing the entire contiguous United States.

III. ESTABLISHMENT FRAME CONSTRUCTION AND SAMPLE

A. Frame Construction

Since lists of establishments with underground motor fuel storage tanks do not exist, it was necessary to create establishment frame lists for each of the 34 PSUs. As described above, the target universe of all establishments with underground motor fuel storage tanks was divided into three segments. The first segment consisted of establishments which, by the nature of their business, were considered fairly likely to have such tanks. This segment, called the "fuel-related establishments" segment,

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contained gas stations, trucking companies, bus services, auto dealers, marinas, golf courses, airports and other industry groups that use large amounts of motor fuel or dispense it to the public. (See Table 4-2 for a list of these industries.) Also included in this segment were government and military establishments with underground motor fuel storage tanks.

The second sample segment, the large establishment segment, consisted of establishments in all nonfuel-related industries (i.e., those industries excluded from the first segment) that have 20 or more employees. This segment was designed to provide estimates of the number of large, nonfuel-related establishments that have underground motor fuel storage tanks to service company vehicles and private fleets.

The third sample segment consisted of farms. Recent census of agriculture statistics indicate that about half of the more than two million farms in the United States have on-farm motor fuel storage, but no information existed on how much of this fuel storage was in underground tanks. This segment was designed to provide estimates of the number of farms that have underground motor fuel storage tanks to service farm equipment.

To construct the first list of fuel-related establishments, several sources and methods were used. A listing of all establishments with a primary or secondary Standard Industrial Classification code appearing on the list in Table 4-1 was purchased from National Business Lists. By specifying firms with a fuel-related SIC code as the secondary code, we included such establishments as convenience stores which also sell gasoline. This list was supplemented by adding any establishments with such a code as their primary or secondary code appearing on the large establishments list, purchased from another source. To complete the fuel establishments sampling frame, lists of government

(Federal, State and local) and military establishments with eligible tanks were needed. The Department of Defense provided lists of military tank locations in the sampled PSUs to the EPA. The civilian government list was constructed using a telephone contact and network approach for the government officials serving the sampled PSUs at the local, State and Federal levels. The frames for all 34 PSUs had about 34,000 entries.

The large establishment list was purchased from Dun and Bradstreet. All establishments in the 76 counties with 20 or more employees were purchased from the Dun's Market Indicators list, a very complete business listing. As noted above, all establishments on the purchased list with a fuel-related primary or secondary SIC code were removed from the large establishments frame and clerically compared with the existing fuel establishments frame. If they were not already on that frame they were added to it. About four percent of the final fuel establishments frame came from the Dun and Bradstreet list. All establishments with an agricultural SIC code were also removed from the large establishments frame and added to the farm frame if not already there. In this way, the particular establishments were on the correct frame and duplication between frames was ruled out. The final count for the large establishments frame in the 34 PSUs was about 68,000 establishments.

The farm frame was provided to the EPA by the U.S. Department of Agriculture (USDA). As noted, it was supplemented by the (very few) farm establishments found on the purchased Dun and Bradstreet list of large establishments. About 31,000 farm owners and operators were listed on the farm frame for the 34 PSUs.

B. Establishment Sample Draw

The fuel establishment sample was drawn by survey region. The total sample size of 800 eligibles was allocated among the six regions in proportion to their count of fuel-related establishments in the 1981 County Business Patterns data. Based on initial field results of 50 percent eligibility, the target sample sizes were approximately doubled. Within each region an equal probability sample was drawn. Table 4-3 gives the counts of sampled cases by region.

The large establishments and farms were both sampled on an equal probability basis nationwide. Six hundred of each were sampled, with only the eligibles remaining in the survey. Because so little was known regarding incidence of underground motor fuel storage tanks in these sectors, the initial sample size was fixed rather than the final number of eligibles being fixed.

Table 4-4 shows the results of screening the initial sample. Eight hundred fuel establishments and 76 large establishments were eligible for the survey (in business and operating an underground motor fuel storage tank). Of these, 871 provided questionnaire data. In addition, 20 of the 600 sampled farms had underground storage tanks. As indicated in Appendix G, about half of all farms report motor fuel storage, but only about 10 percent have more than 1,000 gallons of storage capacity. For these small amounts of fuel, above ground storage is often a reasonable alternative.

Table 4-3. Initial sample sizes for fuel establishment, large establishment and farm samples by survey region

Survey region	Fuel establishments	Large establishments	Farms
1 Northeast	449	158	11
2 Southeast	415	116	88
3 Midwest	325	142	324
4 Central	194	68	142
5 Mountain	75	29	33
6 Pacific	160	87	2
Total	1,618[1]	600	600

[1] Subsequent fieldwork determined that six of the sampled fuel establishments were duplicates.

Table 4-4. Number of eligible cases for fuel establishments, large establishments, and farm samples by survey region

Survey region	Fuel establishments	Large establishments	Farms
1 Northeast	225	21	0
2 Southeast	197	18	3
3 Midwest	161	13	5
4 Central	92	7	5
5 Mountain	42	4	4
6 Pacific	83	13	0
Total	800[1]	76	20[1]

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[1] Five fuel establishments and one farm refused at the interview phase of the survey.

IV. SUB-SAMPLE OF ELIGIBLE ESTABLISHMENTS FOR PHYSICAL TANK TIGHTNESS TESTS

Since so few farms screened had underground motor fuel storage tanks, it was decided to physically test all such tanks at all eligible farms. At the time of sample allocation, it was estimated that there would be at most 50 tanks at eligible farms, so that number was set aside for farm tank tests.

This left a target number of 450 tanks or manifolded tank systems to be tested in the business and government sector (fuel and large establishments). The 450 were allocated to the six survey regions in the same proportions as the original establishment sample allocation, except that a minimum number, 40, were allocated to Region 5, the smallest region, before allocating the remainder to the other five regions. As each region was completed by the interviewers, a list of eligible government, fuel-related establishments and large establishments in the questionnaire sample was constructed, with the number of tanks or manifold tank systems for each establishment listed. At the time of sub-sampling it was assumed that a manifolded tank system (two or more tanks connected by various lines and pipes) would be physically tested as one unit. Therefore the sub-sample was drawn on that basis. During the actual testing, some such systems were isolated, and the individual tanks (and associated lines) were tested separately. Thus, the total number of possible tank tests is more than the number of tanks or tank systems reported here but less than the total number of tanks at these establishments.

The sub-sample of tanks to be tested was drawn on an establishment basis, with all tanks at a given establishment tested. The establishment list for a given region was sorted by number of tanks or tank systems, then PSU, and then fuel-related

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and government versus large establishment. The target number of establishments to select was calculated from the list, which included initial sampling weights, and the target tank sample size, using the weighted average number of tanks per establishment. An equal probability sub-sample of establishments was then drawn from the list. Table 4-5 shows the target number of tank tests and the number of establishments sub-sampled with the number of tanks or tank systems at the sub-sampled establishments.

V. CALCULATION OF FINAL SAMPLE WEIGHTS AND VARIANCE ESTIMATION

A. Calculation of Final Sample Weights

1. Questionnaire Weights for Business and Government Establishments

The final questionnaire weights for establishments sampled with fuel-related SICs other than gas stations were based on a ratio adjustment of the initial sample weights for all such screened establishments to 1982 County Business Patterns (CBP) counts of these SICs followed by a nonresponse adjustment among the eligible other fuel-related establishments to account for the few nonrespondents. (By the time final weights were being calculated, the 1982 data were available.) The adjustments were made by survey region. The ratio adjustment served to calibrate the initial sample to CBP estimates of the number of establishments with one of the fuel-related SICs in each region. The sum of the weights of the eligible cases is the survey estimate of the number of such establishments with eligible tanks, by region. The nonresponse adjustment assures that the

Table 4-5. Summary of business and government establishment subsample[1] for tank tightness testing, by region

Region	Target number of tank systems[2] to subsample for business and government sectors	Number of business and government establishments subsampled	Number of business and government tank systems[1] at subsampled establishments
1 Northeast	115	51	112
2 Southeast	110	47	111
3 Midwest	90	38	86
4 Central	50	23	52
5 Mountain	40	17	43
6 Pacific	45	22	46
Total	450	198	450

[1] All eligible farm underground motor fuel storage tanks were assigned for tightness testing. There were 20 eligible farms with 35 tanks.

[2] In allocating and drawing the subsample of establishments for tightness testing, a manifold tank system was counted as one unit. Some such systems were separated for physical testing.

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weighted results based on questionnaires received equals the estimates based on screening results.

The gas stations were weighted in the same way. First the initial sample was ratio-adjusted by region to CBP totals for gas stations (SIC code 5541). The sum of the weights of eligible cases then estimates the number of gas stations with eligible tanks, by region. A nonresponse adjustment again assures that the weighted results based on questionnaires received will equal the estimates based on screening.

The sample sector of establishments with 20 or more employees in industries not otherwise sampled (the large establishments) was weighted the same way as the gas stations and other fuel-related industries. The CBP totals of establishments of this size in all but the selected fuel-related SICs were used for a region-by-region ratio adjustment of the initial sample. The weighted eligible large establishments then estimate the number of such establishments with eligible tanks in the country, by region. Since all eligible large establishments participated in the interview phase of the survey, no nonresponse adjustment was needed.

No national statistics are currently available to estimate the number of individual government agencies with underground motor fuel storage tanks, which is the universe our frame was built to cover. Therefore no ratio adjustments can be made. Nonresponse adjustments were made to account for the small amount of nonresponse among government establishments.

2. Physical Test Result Weights, Business and Government Establishments

After calculating final questionnaire weights for all responding business and government establishments as described above, the sampling weights for establishments chosen for physical testing were adjusted to sum to the estimated totals for four establishment types (government, gas station, other fuel-related, and other industry) by region. This adjustment was made by an iterative raking procedure,in which the weights were adjusted first to regional totals, then to establishment-type totals, then readjusted to regional totals, and so forth, until no further adjustment was needed. (This took five and a half iterations to achieve.)

A final adjustment was made for tank test result weights. The weight for the individual tank or tank system test would be equal to the establishment physical test weight, except that some tanks were not tested. Thus, a "tank nonresponse" adjustment was made to the tank weights to account for the untested tanks.

3. Farm Questionnaire and Physical Test Weights

Due to the distribution of farms within the survey regions (both overall and in our sample) and the low yield of eligible farms from the screening, the survey regions have been consolidated into three areas for calculating final weights for farms. (See Appendix G for a more detailed discussion.) These are: (1) East (combines survey regions Northeast and Southeast); (2) Midwest; and (3) West (combines survey regions Central, Mountain, and Pacific). Total counts of farms for these areas were obtained from the 1982 Census of Agriculture and used to

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form ratio adjustments for eligible farms. Due to one refusal among farms, a nonresponse adjustment was also made.

Since so few farm tanks were tightness tested (21 of 35 -- most not tested were smaller than 1,100 gallons), no weighted estimates will be presented for that data, and hence no final weights were calculated for physical test results for farm tanks.

B. Variance Estimation

National estimates from the survey are based on a sample of cases rather than a complete census of the nation's underground motor fuel storage tanks, so they are subject to variability termed sampling error. This is due to the fact that drawing several samples would result in different sets of establishments being interviewed and different national estimates. Since the sample was drawn on a probability basis, it is possible to use the survey data to estimate the magnitude of this sampling error. Due to the complex nature of the sample design, this variance is not easily expressed as a simple mathematical formula. It has therefore been estimated by a more empirical approach.

The method of variance estimation used in this survey is termed the jackknife approach. Essentially, a series of subsamples of the survey data known as replicates are created. Using the same series of steps given above for the full sample, each replicate is given weights which can be used to create national estimates based on that replicate. The variance of the replicate estimates of the statistic from the full sample estimate estimates the sampling error of the statistic.

In this report the sampling error is generally reported in terms of 95 percent confidence bounds. These are interpreted as being the numeric range which one can be 95 percent confident includes the true value of the statistic. It is centered on the full sample estimate and its width is determined by the estimated sampling error of the statistic.

SECTION 5

FIELD PROCEDURES -- QUESTIONNAIRE AND INVENTORY

Interviewing fieldwork for the Underground Storage Tank Survey began December 2, 1984. A staff of eight Westat field interviewers was trained to collect data from establishments selected in 34 PSUs nationwide. The interviewing phase concluded on June 29, 1985. This chapter includes some details about the field procedures, inventory data collection and followup procedures used for the survey. Interview and inventory response rate statistics are reported. The detailed summary of the fieldwork is found in Appendix B.

I. WESTAT SCREENING PROCEDURES

The sample of 600 farms and 600 large establishments was pre-screened for survey eligibility by telephone. Telephone interviewers contacted the owner or operator of the farm or business and asked if there were any underground tanks used to store motor fuel at the establishment. All establishments that could not be reached by telephone were included in the interviewer assignment lists to be located and screened in the field.

Establishments selected from the fuel-related sample frame (such as gas stations, government facilities, and trucking facilities) were screened for survey eligibility by the field interviewers.

After the screening procedures were complete, survey materials were mailed out, beginning with all sampled establishments in Survey Region 6 (West Coast). Each establishment was sent a survey package (Appendix F) including an introductory letter, a copy of the survey questionnaire, an instruction booklet, and forms for collecting tank inventory data. The owner or operator was to review the materials to prepare for the next phase of the survey in which a Westat field interviewer visited the establishment and conducted an in-person interview with the respondent. Packages were mailed according to the schedule of the field interviewer so that the respondent received the materials two weeks prior to the interviewer's arrival on site. This gave the respondent time to prepare for the in-person interview.

II. DATA COLLECTION PROCEDURES

The first phase of fieldwork in a PSU was the field screening of the fuel-related sample of establishments. Establishments were found to be ineligible for the survey for various reasons; most commonly, they had no underground motor fuel storage tanks, they were out of business, they were out of area or scope of the survey, or the only tanks at the establishments were abandoned (i.e., out of service permanently). In-person interviews where scheduled with the owners or operators of all eligible establishments within each PSU. When an owner or operator refused to participate in the survey, the interviewer informed the respondent that EPA would be notified, and contacted a Westat field director immediately. An attorney with EPA's Office of Enforcement and Compliance Monitoring was then notified by Westat and necessary action was taken. Questionnaire and inventory refusal rates are discussed in Subsection III.

After the field interviewer arrived at the establishment site, the data collection procedures began with the administration of the Operator's Questionnaire (Appendix F). The respondent received a copy of this questionnaire in the survey package and was to have completed it prior to the interview. The questionnaire gathered basic data about the establishment, its operating characteristics and its tanks.

The interviewer then reviewed the inventory forms and procedures with the respondent. The inventory record-keeping procedure involved taking and recording dipstick readings and meter readings (if the dispensers were metered) for 30 days. Any deliveries made during that time period were also recorded. The interviewer checked to see that the inventory forms were being filled out correctly and that all tank and meter numbers on the forms and in the questionnaire corresponded to one another. If previously collected inventory records were used, the interviewer made sure 30 complete readings were provided.

Once all inventory sheets were reviewed and tank and meter numbers verified, the interviewer checked the accuracy of all dispenser meters using a five-gallon Certified Standard Weights and Measures Calibration Can. Five gallons of fuel was pumped into the test can and by reading the level of fuel according to the measuring gauge on the front of the can, the interviewer was able to determine the calibration ratio that would correct for any error in the meter. The inventory records were adjusted prior to inventory reconciliation analysis to account for the meter error.

After the meter accuracy check, the interviewer measured the diameters of all tank fill pipes, determined whether or not there were drop tubes present inside the fill pipes and, if present, whether the drop tube was permanent or removable. This data was collected to aid tank testing crews in preparing for tightness tests at selected establishments.

Before leaving the site, the interviewer located the underground storage tanks on U.S. Geological Survey maps, which were provided for each PSU in the survey. The interviewer also evaluated the overall status or attitude of the on-site interview by answering debriefing questions.

III. FIELD INTERVIEW DATA COLLECTION STATISTICS

Table 5-1 contains data collection statistics for the field interview portion of the survey. It covers statistics on interview and inventory response and refusal rates.

A. Interview Response Rate

The interview response rate for this mandatory survey is nearly 100 percent overall, as well as for each sample segment. Out of 2,800 establishments contacted, 896 had underground motor fuel storage tanks, and were therefore eligible for the survey. Of those, 890 or 99.3 percent completed interviews. The highest response rate among the sample segments was among the large establishments, where 100 percent of the eligible establishments provided interview data.

Table 5-1. Field interviewing and inventory status statistics

	Farms	Large Estab-lishments	Fuel Estab-lishments	Total
A. Number sampled	598[1]	600	1,612[2]	2,810
B. Number contacted	596	596	1,608	2,800
C. Number of establishments contacted that have tanks ("eligibles")	20	76	800	896
D. Number of interview responses	19	76	795	890
E. Response Rate (percent of eligible respondents who completed interview	95%	100%	99.4%	99.3%
F. Number of interview refusals	1	0	5	6
G. Refusal rate (percent of eligible respondents who refused interview)	5%	0%	0.6%	0.7%
H. Number of inventory responses (includes both complete and partial complete)	7	60	630	697
I. Response rate (percent of eligible respondents who returned inventory)	35%	79%	78.8%	77.8%
J. Number of inventory refusals	6	1	8	15
K. Refusal rate (percent of eligible respondents who refused to record inventory)	30%	1.3%	1%	1.7%
L. Number of delinquent inventory responses	4	9	131	144
M. Number of establishments for which inventory measurements are impossible	3	6	31	40

[1] 600 farms were sampled. Two farms were found to be duplicates in the telephone pre-screening.

[2] 1,618 fuel establishments were sampled. Six were found to be duplicates in the field screening.

B. Certification of No Tank Status

Since many of the sampled establishments had been selected based on being in an industry expected to have underground motor fuel tanks, a verification program was undertaken for establishments which responded to the initial contact by stating that they had no eligible tanks (i.e., non-empty, underground, and storing motor fuel). For Region 6, the West Coast, which was the first region fielded, the field interviewer went to each of these establishments in person to visually confirm the statement and to get the owner or operator's signature on the "Certification Statement for Establishments Without Tanks" (a copy of which appears in Appendix F). This experience showed that those respondents initially stating they had no tanks were correct. For the remainder of the survey, the personal visits were not made to all such respondents, but they were all asked (by mail) to sign and return the no tank certifications. Signed statements were received from 80 percent of the "no tank" ineligible respondents.

C. Inventory Response Rate

Nearly 78 percent of the eligible establishments have furnished complete or partial complete inventory data. Even this relatively low response rate (compared with other parts of the survey) was achieved only after extensive edit and followup efforts by Westat's survey staff and finally a stern warning letter from EPA. Sixteen percent of the eligible establishments have not yet provided inventory records. It was impossible for 4.5 percent of the eligible establishments to keep inventory records.

D. Problems Encountered in Recordkeeping

A majority of establishment operators were unable to provide inventory data that was useable for inventory reconciliation analysis techniques without technical assistance. Establishment operators received detailed written instructions on inventory recordkeeping procedures, and on-site training was provided by the survey interviewers.

Nevertheless, almost 80 percent of the operators supplied inventory data sets that were incomplete or incorrect, initially. Extensive mail and telephone recontacts were made to the operators to attempt to capture the missing information and correct the problems. Eventually about half of the responding establishment operators were finally able to provide inventory records complete enough for analysis.

These experiences suggest that many establishment operators lack skill, training and/or motivation to correctly follow inventory recordkeeping procedures. Problems encountered with inventory records are listed in Table 5-2.

IV. FOLLOWUP PROCEDURES

Followup procedures were implemented to complete interviews which could not be completed during the time the interview team was working in a PSU and to make sure as many eligible establishments as possible returned useable inventory data.

A "clean-up" interviewer followed behind the field interviewers to complete interviews that could not be scheduled

Table 5-2. Problems encountered in inventory recordkeeping

Major problem areas	Percent of establishments with this problem
1. Meter sales and gallons used as calculated from stick readings and deliveries are equal (respondents adjusted out the daily variances)	19%
2. Did not provide inventory for the total 30 days	15%
3. Did not use the form correctly such that data was unusable	8%
4. Carried readings down from closing to opening (tanks without meters)[1]	7%
5. Did not provide enough complete readings (some stick or meter readings missing)	6%
6. No inch-to-gallons conversions provided	4%
7. Inconsistent conversions (from inches to gallons)	4%
8. No meter readings provided	3%
9. No stick readings provided	3%
10. Problems with delivery records	2%
11. Reported readings greater than tank capacity	1%

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[1] For tanks without meters, the inventory recording procedure involves sticking the tank before and after each inactive period. This procedure is counter-intuitive to most respondents, who cannot understand the value of measuring and recording what they regard as measurement error in the second reading. Most respondents using "Tank Without Meter" forms have, therefore, measured the level in the tank only after each use (before each inactive period), and have (incorrectly) carried the readings to the "after" columns.

SECTION 6

TANK TESTING FIELD PROCEDURES

The field testing phase of the national survey required collecting descriptive information from each test site, conducting tightness tests on the tank systems and associated piping, and collecting ancillary environmental data. MRI managed the field testing and data acquisition, developed and maintained the test schedule, and served as the primary contact with the establishment owner/operator (o/o). The three-person field teams were comprised of an MRI field data technician and a two-person tank test crew provided by a commercial tank testing firm under subcontract to MRI. The tank test crews were provided by O.H. Materials, Inc., Double Check Company, Inc., and Protanic, Inc. This section describes the procedures used to accomplish the field data collection. A more detailed description of the field testing procedures may be found in MRI's Test and Analysis Plan.[1]

I. PRE-TEST PREPARATIONS

Preparations for field data collection at each establishment were initiated soon after the site identification and survey questionnaire results were received from Westat. The questionnaire responses and site diagrams were reviewed and a preliminary test date was assigned for each site. Tests were scheduled to maximize efficient use of the field teams and to complete the

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[1] "Test and Analysis Plan for the Tank Testing Program of the National Survey of Underground Storage Tanks," H.K. Wilcox, J.W. Maresca, Jr., J.D. Flora, C.L. Haile, June 10, 1985.

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survey as expeditiously as possible. Key scheduling considerations were the geographic locations of the sites, the number of tank systems at each establishment, and any special problems related to tank testing anticipated from the survey questionnaire results. Because up to three tank systems could typically be tested each work day at a single establishment, one day was allocated for sites with three or fewer tank systems. Similarly, two days were allocated for sites with four or more tanks. However, as testing three systems in a single day generally required significant overtime, consecutive three-system days were avoided where possible. Days were also incorporated into the schedule for makeup tests.

As soon as possible following assignment of a preliminary test date, the o/o was contacted by phone to arrange the test appointment. The testing and data collection program were fully explained and a mutually agreeable test date was established. The o/o was also instructed how to file compensation claims to EPA for costs incurred due to closure for testing.

The key requirements of the tightness testing were that the system be removed from service during the test and that the tanks be completely filled. Several gallons of additional product were also required to top off the tank during testing. If the o/o was unable to arrange product delivery to accommodate the test requirements, assistance was provided in the form of contacts to the appropriate fuel supplier.

The field crew assigned to a specific site contacted the establishment o/o by phone or visit approximately two days prior to the scheduled test date. This contact served to confirm the test date, confirm that the establishment would be ready for testing, and answer any additional questions from the o/o.

II. SITE DESCRIPTION INFORMATION

A site inspection was conducted at each establishment during the test visit prior to or during setup of the tank system test equipment. The purpose of the inspection was to provide an accurate-detailed record of the layout of the establishment, tank system configurations, and environmental features that may be related to system failure or leakage. This information was recorded in the form of overall site sketches, detail sketches for each tank, and a table of critical features. The site sketches recorded the layout of tank systems and dispensers as well as locations of buildings, roads and pavements, power lines, and waterways. Color instant print photographs were taken to supplement descriptions contained in the sketches. The following details were recorded on a critical features data form for each tank system:

Survey ID No.
Tank number
Product type
Number of dispensers
Tank size
Size of fill pipe
Size of gauge pipe
Size of stick pipe
Drop tube - permanent or removable
Delivery system - pressure, suction
Depth of tank from grade
Surface over tank
Presence of overhead power lines
Presence of nearby waterways

III. TANK SYSTEM TIGHTNESS TESTING

After the evaluation of a number of tank tightness test methods (see Appendix C), it is clear that none of the standard test methods evaluated in the program can consistently and reliably achieve detection of the 0.05 gallon per hour leak rate specified by the NFTA 329 "Recommended Practices for Underground Leakage of Flammable and Combustible Liquids, 1983." This conclusion is based entirely on the data collected during the method selection phase of the program, since supporting data which was requested from the test companies to document their performance claims was not received. EPA modified, for use in the survey, one of the tank test methods to improve the accuracy of the test results.

While some methods can provide reliable results under some specific conditions, there are many situations which commonly occur in the test environment (such as the presence of a water table) which can invalidate the test results. Unless the test crew takes specific steps to identify these conditions, the reported results may be either misleading or incorrect. Most test methodologies currently in use fail to take definitive steps to identify one or more of these problem areas. The test results obtained must therefore be suspect to the degree that these factors are not recognized. The effects can be substantial and cannot be generally evaluated from the test data after the test crew has left the test site.

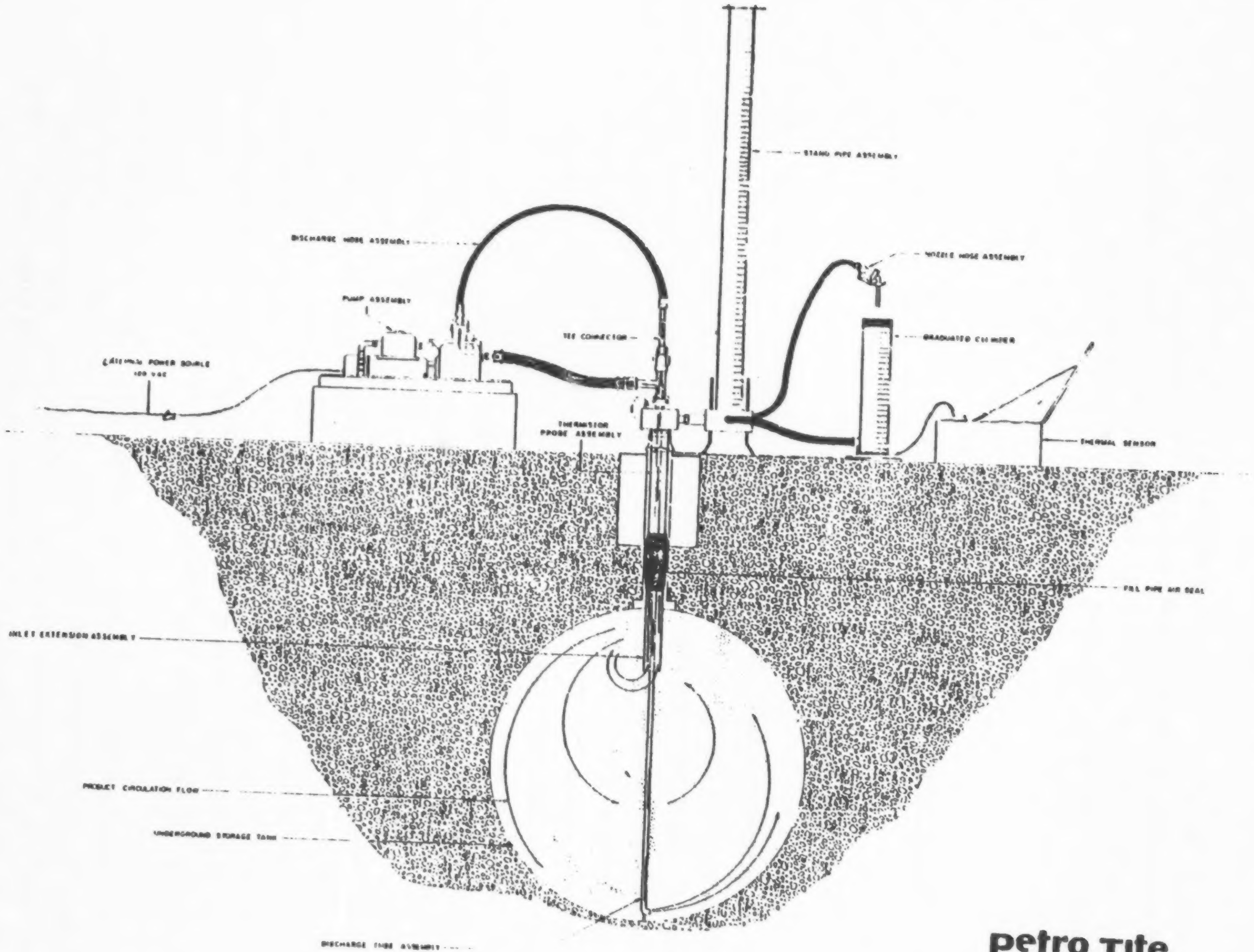
One of the major objectives of the program prior to the national survey was to identify and characterize a test method suitable for use on the program. A modification of the Petro-Tite method was developed and characterized for this purpose. This method was selected as the method with the most consistent approach to identifying potential problems and taking action to correct for them. It was judged to provide the most consistenyly reliable data for the national survey. It has stated procedures to identify and correct for tank end deflection, temperature effects, water table, and vapor pockets. EPA modified the method in three ways in order to improve accuracy: (1) the test time and sample frequency were increased; (2) the temperature correction algorithm was improved; and (3) statistical hypothesis testing procedures were applied to the data to determime leak status.

A. System Test

1. Method Description

The Petro-Tite tank test measures product loss from the tank system by monitoring the change in product level in an elevated standpipe. Apparent volume changes are corrected for expansion and contraction caused by product temperature changes during the test to produce a net volume change. The net volume change over time is equivalent to the leak rate. The key features of the Petro-Tite method are that the test is conducted with the tank overfilled into an elevated standpipe and that the product is circulated during the test. The reference level in the standpipe is set to maintain a hydraulic pressure, or fuel head pressure, of 4 psig on the bottom of the tank in excess of any back pressure caused by groundwater at a level above the tank bottom. The purpose of conducting the test at an elevated pressure is to increase the probability of detecting small leaks, to mitigate masking of leaks by groundwater back pressure, and to stabilize end cap deformation. The product is circulated during the test to produce and maintain temperature homogeneity.

The Petro-Tite tank test equipment is shown in Figure 6.1. A probe, inserted into the fill tube, consists of the circulation pump inlet and discharge tube and a thermistor assembly. The probe is sealed in the fill tube with an air bladder seal. The


DISCHARGE HOSE ASSEMBLY
STAND PIPE ASSEMBLY
NOZZLE HOSE ASSEMBLY
PUMP ASSEMBLY
TEE CONNECTION
GRADUATED CYLINDER
EXTERNAL POWER SOURCE
120 VAC
THERMISTOR PROBE ASSEMBLY
THERMAL SENSOR
FILL PIPE AIR SEAL
INLET EXTENSION ASSEMBLY
PRODUCT CIRCULATION FLOW
UNDERGROUND STORAGE TANK
DISCHARGE TUBE ASSEMBLY

Petro Tite
TANK TESTER

THE HEATH COMPANIES

Figure 6-1. Test equipment

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circulation pump withdraws product from the fill pipe and discharges it through a jet nozzle located near the bottom of the tank. The nozzle is directed at a 45-degree angle down the longitudinal axis of the tank to produce a swirling circulation. The thermistor is located at the pump inlet and is connected to an electronic thermal sensor module to provide temperature readout. The standpipe is connected to the probe and also to a graduated cylinder. During the test, the product level in the standpipe is readjusted to the reference level using the graduated cylinder. The volume of product added to or removed from the standpipe to reach the reference level is measured from the cylinder by difference, i.e., volumes in the cylinder are read before and after raising the standpipe level to the reference mark.

2. Method Operation

At the beginning of the test, the probe and thermistor units were installed into the fill pipe and the circulation was initiated. A small bore hole was drilled near the tank, preferably in the tank backfill, to determine if and at what level the water table was above the bottom of the tank. The density and temperature of the fuel product was determined with a hydrometer and a thermometer. The product temperature and density were used to determine the thermal expansion coefficient for the fuel from physical properties tables prepared by the American Petroleum Institute. The product density and depth to the water table were used to determine the standpipe reference levels.

The standpipe and graduated cylinder were installed and product was added to the standpipe to a "high" level reference level to place a pressure of 5 psig on the tank bottom. Product was periodically added to maintain this level until the rate of change indicated that end cap deformation had stabilized. Then, the level was lowered to the "low" level to place 4 psig on the tank bottom. This was the reference level for the leak rate test.

The product level in the standpipe was readjusted to the reference level at 5-minute intervals. The volume of product in the cylinder before and after releveling were recorded on the test data sheet. Fuel temperature readings were made and recorded on the test data sheet at 5-minute intervals. These data were also entered into a LOTUS 123 (tm) spreadsheet file on a portable microcomputer. The test was conducted for 2 h with readings at 5-minute intervals. The tank system leak rate was calculated using the volume change, temperature data, tank volume, and thermal expansion coefficient of the product. At the conclusion of the system test, a line test was conducted. After completion of the line test, the equipment was removed from the tank.

Where possible, the entire tank system was tested as a single unit. This included vent lines, distribution lines, and, in the case of multiple tanks manifolded into a single system, all tanks and syphon lines. However, in cases where vapor pockets were found or the piping layout was not well known, tanks were isolated and tested separately. Isolation of tanks from associated piping generally required excavation to expose the top of the tank.

Vapor pockets were also indicated in several single tank systems. Vapor pockets were suspected when the standpipe level fluctuated in an apparent haphazard manner. This was typically caused by vapor trapped in manway or piping on the top of the tank. In cases where vapor pockets were indicated, the top of the tank was exposed by excavation and air bleed valves were installed on manway and bung covers. The vapor was bled from the filled tank and normal tank tightness test was conducted. Identification of vapor pocket problems and the need for excavation could not be identified until the tank test was attempted. Hence, testing tanks with vapor pocket indications generally required at least two test days.

3. Performance Characteristics

The performance characteristics of the Petro-Tite test method were empirically determined during the survey by examining the variance within specific tests, and between retests on 34 pairs of data. The total variance was found to be 0.00264 gal^2/h^2 which represents a standard error of ± 0.0514 gallons per hour. This procedure is covered in Appendix D of this report.

B. Line Tests

Tightness testing was conducted on the distribution lines where possible. The system requirements for conducting a line test are a suitable connection at the delivery end of the line to install the test unit and a check valve in good working order. The check valve, typically installed at the inlet of the distribution line in the tank (foot valve) or in the line just above the tank (angle check valve), prevents product in the line from draining back into the tank. Hence, the location of the check valve determines the portion of line subjected to the test.

1. Method Description

The Petro-Tite line test system pressurizes the system with product and measures the volume of product required to maintain the reference pressure. Lines for pressure and suction distribution systems are tested in a similar manner, although the test pressure differs. A diagram of the line test system is shown in Figure 6.2. The test unit is connected to the delivery end of the distribution line and the line is pressurized using a foot operated pump to 15-30 psig for suction lines or 30-80 psig for pressure lines. This pressure closes the check valve to prevent fuel loss back to the tank. The pressure is monitored using the gauge and the pressure restored periodically. The volume of product required to restore the reference pressure is recorded.

2. Method Operation

The line test was conducted at the conclusion of the tank system test, before the tank test equipment was removed. Air was bled from the line and the test unit was connected to the distribution line. Product was pumped into the line to achieve the required pressure. The product level in the tank test standpipe was monitored simultaneously to determine if the foot valve was functioning properly. If product loss from the line was observed as a volume increase in the tank test standpipe, the check valve was considered leaking and the line test was inconclusive. If possible, the check valve was replaced and the test repeated.

The line set pressure was monitored and restored using the test pump at 15-minute intervals. The product level in the graduated reservoir was recorded before and after each pressure restoration. The total product volume added during the 1-h test

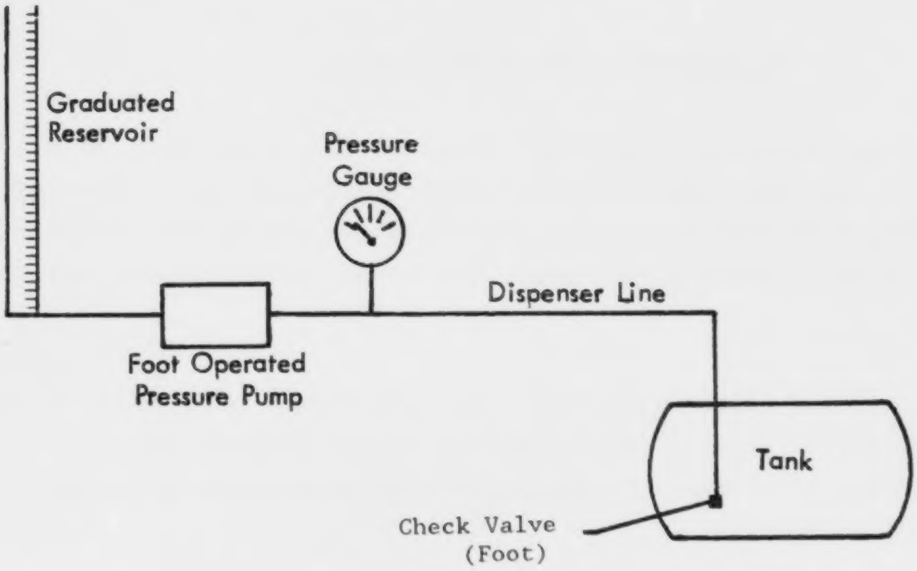
Graduated
Reservoir
Pressure
Gauge
Dispenser Line
Foot Operated
Pressure Pump
Tank
Check Valve
(Foot)

Figure 6-2. Line test equipment

(a total of four 15-minute interval readings) was reported as the line leak rate. If the volume required to restore pressure is less than 0.025 gallons per hour for suction lines or 0.010 gallons per hour for pressure lines, the line is considered to be tight. Volumes greater than these indicate that the line is leaking or an invalid test.

3. Performance Characteristics

The performance characteristics of the line leak detector have not been verified by independent measurements. However, expert users of the device have stated its tolerance to be at least ± 0.0005 gallons per hour when used on a typical delivery line.

The average standard error of line tests conducted on the national survey was of the order of 0.001 gallons per hour. This is more than an order of magnitude more sensitive than the threshold leak rate.

Four situations can occur which can cause volume changes. These are: leaks (or a bad check valve); changes in the liquid temperature in the line; line expansion or stretching due to the high pressure; and compression or shrinkage of air vapor present in the line. All of these produce characteristics which can be recognized by experienced personnel.

The two problems which caused the large number of line leaks to be declared invalid were bad check valves and air pockets. Ninety-one tests were declared to be invalid for these reasons. In order to complete the testing on the 77 systems with bad check valves, it would have been necessary to excavate the top of the tank in most cases. This was beyond the scope of survey.

At the conclusion of the line test, the pressure on the line was released and the product allowed to flow back into the graduated reservoir. The bleed back volume was also measured. A bleed back volume of greater than 0.050 gal indicated air in the line and the test was considered inconclusive. The test was repeated after air was bled from the line. If the repeat test also had excessive bleed back, the test was considered inconclusive.

IV. ENVIRONMENTAL DATA COLLECTION

General environmental data were also collected during the tank system and line testing. These data included the following:

Ambient air temperature
Surface temperature above the tank
Subsurface soil temperature
Barometric pressure
General climatic conditions
Water table level.

These data were collected to provide a record of any external temperature and pressure conditions that may have an effect on the operation and results of the system and line tightness tests.

All environmental data except the water table level were recorded hourly during the test visit. The water table was typically determined by drilling a bore hole through the tank backfill material to the depth of the tank bottom. If water was not encountered at that depth, it was recorded as being lower. Anecdotal information concerning seasonal or other periodic fluctuations were recorded as available. The ambient air temperature was measured using a mercury-in-glass thermometer. Surface temperature was also measured with a mercury thermometer placed on the surface at grade level over the tank. A thermistor inserted into the bore hole previously drilled to determine water level was used to monitor subsurface soil temperature. Barometric pressure was measured with an aneroid barometer. General climatic conditions, based on the observations of the field technician, were recorded in common climatic terms such as: light and variable winds, foggy, light rain, or sunny.

V. Tightness Testing Field Experience

A. Test Completion

A summary of the tests completed is presented here. There were 485 manifolded tank systems from which 560 tanks were selected for tightness testing. However, about 10 percent were not tested because they were found to be out of scope or untestable for technical reasons, or testing was refused by the facility owner/operator. Out-of-scope tank systems consisted of a closed fuel service station, small tank systems on farms (i.e., less than 1,100 gallons), and one system at an establishment that had been misclassified. Technical problems included several unused tank systems containing a residual sludge and tank systems installed that did not permit access to install an air bleed valve when vapor pockets were indicated. Some of the latter cases included tank systems without bungs on the top and tank systems installed under a building. A tank system installed under a hospital helicopter emergency landing pad was considered untestable due to the lack of an alternate landing location. The final refusal rate was 3 percent.

B. Technical Problems

A summary of the technical problems encountered in tank system and distribution line testing is presented in Table 6-1. Fuel delivery problems and vapor pockets were the most disruptive to the test schedule. Coordination of fuel delivery scheduling with the test schedule was a significant part of the test preparation effort. In spite of extensive preparation, failure of the supplier to deliver product as scheduled caused delays in 19 tests. Vapor pockets were indicated in 21 tests. These required exposing the top of the tank by excavation and installation of air bleed valves.

Many of the other problems involved features requiring resolution to permit installation of the test equipment or mitigation of vapor pockets. Permanent drop tubes, vapor recovery systems, and pumps were removed and remote fill pipes were excavated and disconnected to facilitate installation of the test equipment. Manifolds were disconnected to mitigate vapor pockets and to allow separate testing of individual tank systems in some manifolded tank systems. Failure of foot valves was a frequent problem encountered during distribution line testing. Also, excessive bleed-back volumes, indicating air in the distribution line, caused 14 line tests to be considered unreliable.

Table 6-1. Technical problems summary

Problem	Number[1]
Fuel delivery	19
Vapor pockets	21
Permanent drop tubes	17
Vapor recovery systems	6
Pump	2
Remote fill pipe	2
Manifolds	14
Other	23
Foot valve failure	77
Excessive bleed-back volume	14

[1] More than one problem could be encountered in a given test. Hence the total number of problems is greater than the number of tests with any problem.

SECTION 7

TANK TESTING DATA REDUCTION AND QUALITY ASSURANCE (RETEST) RESULTS

This section describes the statistical data reduction process whereby the raw data generated by physical tank tightness tests in the field were converted into estimates of volume change rates under test conditions for tank systems (vessels plus piping). It then gives results of the quality assurance retests which help in judging the overall accuracy of the physical test and data reduction process. Note that throughout this Section of the report, quantitated volume change rates are given as measured under test conditions and are not adjusted from test pressures to operating pressures.

I. DATA COLLECTION AND REDUCTION

A. Data Collection and Transmission

Raw data of volume and temperature change at five-minute intervals were collected for a two-hour period during the physical test, as described in Section 6. These data were collected in handwritten form on the data sheets normally used by Petro-Tite, and were also entered onto a spreadsheet using a mini-computer at the field site. Data were transmitted from the spreadsheet to MRI by telephone for timely analysis. The diskettes and hard-copy data sheets were shipped to MRI on a weekly basis. The telephone transmission was checked against the diskette, and the diskette against the hard copy to ensure that the correct raw data were entered in the working spreadsheet file, which was then used to estimate volume change rates and their (within-test) variability.

B. Standard Data Reduction

Several statistical analysis methods for reduction of the tank test data were considered for use on the national survey. The test method produced a volume change measurement at five-minute intervals. The other measurement recorded at five-minute intervals was a temperature measurement. The temperature was recorded as a cumulative reading -- the tank temperature -- while the volumes were recorded as differences. In order to make the temperature and volume data comparable, they had to be put in the same form. Either both must be changes or both must be cumulative.

As a result of the considerations of the types of analyses available (see Part III of Appendix D for discussion of possible methods) and the advantages and disadvantages of each, a standard analysis was designed. For the standard analysis, the estimated volume change due to temperature change and the observed total volume change were both expressed in cumulative form, beginning at zero for the start of the test. A straight line through the origin was fit to the temperature-related volume change data by least squares. The predicted values of this line were calculated and used as a smoothed temperature correction for the observed volume changes. The data were plotted and inspected visually for outliers or deviations of the temperature data from linearity. Any questionable data were checked in detail or considered for special analysis.

If no problems with the data were found, the predicted values from the smoothed temperature line were used as the temperature correction. This smoothed temperature correction was subtracted from the observed volume data for each time point. The resulting differences were divided by the time interval to obtain a series of volume change rates expressed in gallons per hour, typically based on a five-minute interval. The arithmetic mean of these rates was calculated and used as the estimate of the volume change rate. In calculating the variance n-1 was used as the divisor, where n is the number of terms in the mean. The result was divided by n to form the variance of the mean. The square root of this is the within-test standard error reported before adjusting for between-test variation. See Part V of Appendix D and Part I of Section 8 for a discussion of the between-test variance.

C. Special Analyses

A number of data set features called for a different or more detailed analysis than that described above. These were dealt with on an individual basis. Occasionally apparent outliers were found. These were checked against the raw data and the test log to see if there was any physical reason for them. A few tests had thermistor boxes fail during the test for some reason (rain, FM interference). These generally gave temperature data that appeared as outliers. When outliers were found and a physical reason identified, the aberrant data were removed from the analysis. This generally required smoothing over the missing data by interpolation. If errors were identified, they were corrected and the analysis redone.

The typical data showed a consistently increasing temperature, generally linear. A smaller proportion of the data sets showed linearly decreasing temperature. Some data sets showed evidence of temperature increase that was curvilinear. If this curvilinearity appeared or was suspected, a test for curvilinearity was done by fitting both a linear and quadratic to the temperature data by least squares (through the origin). If the quadratic improved the fit significantly, the curvilinear fit (using both linear and quadratic terms) was used for smoothing.

A few cases were found where both temperature and volume were not only non-linear, but also not moving consistently in one direction. Provided that they showed the same pattern, analysis proceeded. In this event, a five point moving mean was used to smooth the temperature data. Equal weights were used. This resulted in the loss of four data points; two at the start and two at the end of the test.

Some tests showed volume change rates that were initially increasing rapidly in curvilinear fashion, while the temperature changes were quite linear. The volumes typically increased rapidly for the first few observations, then slowed. This was interpreted as relaxation or tank deformation. The apparent relaxation appeared to follow an exponential curve and to approach the temperature change rate as an asymptote. However, the constant of this differed by tank. The rate of relaxation may be related to the nature of the soil in backfill and water conditions. When this was identified, the initial points exhibiting this relaxation of the tank deformation were deleted before analysis.

D. Criteria for Invalid Data

A few of the data sets from the tank tests were judged invalid based on the analysis of the data. This occurred infrequently (in 6% of test results).

There were a number of criteria for declaring a data set to be invalid. The most common was that the data showed a volume increase even after adjusting for temperature. Since the test method places pressure on the tank, a volume increase cannot occur from inflow of water. Data that showed volume increases after temperature adjustment that exceeded levels that could be reasonably attributed to the variability of the measurement process were judged to be invalid tests. The reason for this is that such an apparent volume increase with no explanation could be eclipsing a small actual volume loss or leak. Generally any tank that showed a volume gain rate of more than 0.1 gallons per hour after temperature adjustment was judged to be an invalid test. The most likely explanation for such tests is that those tanks had trapped vapor pockets.

As described in Section 8 (Part III) and Appendix D (Part VII), at the next stage of analysis, some additional tests were judged to be invalid due to a measured inflow that was excessive when compared with its estimated total standard error, even though the inflow was not as large as 0.10 gallons per hour.

A variety of other data features led to the conclusion that the test was invalid. A few instances were found where the temperature as recorded fluctuated erratically during the test while the volume measurements were relatively stable. If the temperature data were so erratic as to preclude a temperature adjustment, then the test was declared to be invalid.

One or two tests showed both temperature and volume measurements that were erratic and did not appear to track together. These tests were also judged invalid. Such behavior may have been caused by incomplete tank deformation, followed by relaxation, combined with mixing problems. No valid volume change rate could be estimated.

II. RETEST RESULTS

Three types of retests were conducted as part of the national survey of underground storage tanks. One was a back-to-back retest, conducted immediately after the original test used to estimate the volume change rate. The second was a leak simulation test also conducted immediately after the original test. The third type was a complete retest conducted on a different day and generally by a different crew. Each of these types of second testing estimates a different source of variation possible in the tank tests. The leak simulation and back-to-back retests estimate variation of the overall measurement procedure from one two-hour period to the next, with the same set-up, crew, day of the week, and so on, while the complete retests measure variation between tests as well. The initial test result in each case was used as the data for the survey estimate. When the test and retest results differed, the results were examined to discover reasons for the differences. This led to the discovery of the repairs that had been made in two cases. The primary purpose of the quality assurance program was to measure the overall performance of the test, which was accomplished. A list of all of the retests appears in Appendix D, as does a list of the simulated leak retests. A table summarizing the estimates of bias (lack of accuracy) and standard deviation (precision) based on each type of test is presented as Table 7-1. We discuss these three types of quality assurance retests in more detail below.

A. Leak Simulations

The leak simulation tests were conducted after the original test was concluded. Generally they were only conducted when the original test indicated that the tank was tight or had a small estimated volume change. The volume rate used for leak

Table 7-1. Retest results (volume change rates measured under test conditions, not adjusted to operating pressure)

Type	Mean difference (gallons per hour)	N	Variance $(gph)^2$	Mean squared error $(gph)^2$	Standard deviation (gph)	Root mean squared error (gph)
Leak simulation	-0.00891	11	0.00066	0.00074	0.0257	0.0272
Back to back	0.00629	14	0.00053	0.00057	0.0231	0.0239
Retests	0.00297	34	0.00254	0.00255	0.0504	0.0505

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simulation was on the order of 0.1 gallons per hour, so a large observed volume change would overwhelm it.

The purpose of the leak simulation tests was to document that the testing method could detect leaks of known size in tanks that appeared to be tight. In addition, use of the leak simulation allows for an estimate of the accuracy of the test as well as its precision. The accuracy refers to the ability of the test to measure a known volume change, while the precision of the test refers to its ability to reproduce measured rates.

Thirteen leak simulation tests were conducted. Two of these were conducted on tanks that had estimated volume rates that indicated that the tanks were probably leaking (as evidenced by the observed volume changes). These tests were excluded from the analysis because variability is known to increase for leaking tanks.

Three rates were calculated from leak simulations. The first was a baseline rate for the tank. This was estimated during the regular tank test. While the leak simulation was conducted, a measured rate was estimated. This is the rate observed by the testing method during leak simulation. It is presumed to be composed of the tank rate plus the simulated rate. The simulated rate is calculated by collecting product drawn from the tank at a constant rate, weighing it on a triple beam balance, and converting the weight to volume at the temperature of the product in the tank. The difference between the observed rate during the simulation and the baseline rate provides an estimate of the simulated rate. The difference between this and the actual simulated rate can be used to assess the accuracy of the test.

The average difference between the measured rate and the simulated rate was -0.00891 gallons per hour, based on the 11 leak simulations where the tank was not estimated to be leaking (see Table 7-1). Recall that these rates are reported as observed under test conditions and not as adjusted for test pressure. The difference between the measured rate and the simulated rate is interpreted as an estimate of bias. The variance of the differences about their mean provides an estimate of precision. This variance was estimated to be 0.00066 gallons per hour squared. The mean squared error (MSE) is a measure which incorporates both types of error--accuracy and precision. It is calculated as the sum of the bias squared plus the variance. In this case it was 0.00074 gallons per hour squared.

The bias is clearly not significant in that it does not differ significantly from zero (t = -0.347, 10 degrees of freedom). As a result, the variance and the mean squared error are nearly identical. A measure of variation often used is the standard deviation (or root mean squared error if bias is present), which is the square root of the variance (or MSE). This measure has the advantage that its units are the same as the measurement, gallons per hour. The standard deviation (estimating within-test variation)was estimated to be 0.0257 gallons per hour for these data.

B. Back-to-Back Retests

Back-to-back retests were conducted on a total of 18 tanks, which includes the 13 tanks with leak simulations. The purpose of the back-to-back retests was to estimate the stability of the test method. That is, to ensure that the volume change estimate did not differ markedly if based on the succeeding two hours after the test.

As with all of these tests, variability is expected to be larger if the initial leak rate or volume change is larger. For this reason, the results of the back-to-back retests are presented here for the 14 tests with volume change rates less than 0.1 gallons per hour in absolute value. Retest results for tanks with larger volume rates were more variable but generally consistent. (See Appendix D, Part IV for a discussion of these retests.)

The average difference between the original and retest for the 14 tests with small volume changes was 0.00629 gallons per hour. The variance estimate was 0.00053 gallons per hour squared, giving a mean squared error of 0.00057 gallons per hour squared. The corresponding standard deviation was 0.0231 gallons per hour and the root mean squared error estimate was 0.0239 gallons per hour (not adjusted for test pressure). The mean difference was not significantly different from zero (t = 0.272, 13 df).

C. Complete Retests

The complete retests consist of revisits to the site on a different day. Typically this includes a different crew and involves rescheduling and refilling the tank. The complete retests incorporate all of the features of a tank test and so include all the sources of error including potential difference from crew to crew (including differences between sets of testing equipment) and differences due to weather conditions, nearby traffic, day of the week, etc. In addition, there is a possibility that the tank is different at the time of the retest. In fact, two of the retests originally scheduled were canceled when it was found that the tanks had been repaired between the initial test and the scheduled retest. In addition, two retests were performed and it was then discovered that the tanks had been repaired between the initial test and retest. These data are also not included as they would measure an additional source of variation which is not of interest (i.e., repair). Two other retests were performed on tanks that were initially determined to have large vapor pockets. These two tanks were retested later and on retesting were again found to have large vapor pockets. The results of the test and retest for these tanks with vapor problems agreed qualitatively; however, the numerical agreement was not close. The reason for this may be that the vapor pocket trapped in the tank was of different size. There were also different ambient conditions that would affect the vapor differently. For these reasons, the vapor retests were not included in the estimate of the variance from the retests.

The mean difference from the set of 34 relevant retests was 0.00297 gallons per hour. The variance of the difference was 0.00254 gallons per hour squared, giving a mean squared error of 0.00255 gallons per hour squared. The standard deviation of the differences for these 34 retests is 0.0504 gallons per hour and the root mean squared error is also 0.0505 gallons per hour. The mean difference is not significantly different from zero (t = 0.059, with 33 df).

D. Results

The retest data analysis showed no evidence of bias in the test methods. All three retest schemes had very small estimates of bias which were not significantly different from zero. Given the historical leak cut-off of 0.05 gallons per hour, bias of less than 0.01, as was found in all three data sets (less than

0.005 in the largest set) is not of practical concern, in addition to not being statistically significant.

The variability, or magnitude of the measurement error of the physical test can also be assessed using these data. Both the back-to-back retest and the leak simulations estimated within-test standard deviations on the order of 0.025 gallons per hour. The complete retest data gave a standard deviation of 0.05 gallons per hour for the total variability of volume change rate estimates. As is discussed in Section 8, Part I, the difference is probably due to a between-test component of variation which is measured by the retests but not by the back-to-back or leak simulation tests.

In summary, the physical test is accurate (not significantly biased) and has a known precision (total standard error of an estimated volume change) of 0.05 gallons per hour (measured at test pressure and not adjusted to operating pressure). That this standard error coincides with the historical cut-off value for declaring a leak is an interesting coincidence.

SECTION 8

STATISTICAL ANALYSIS OF LEAK DATA AND LEAK STATUS DETERMINATION

Section 6 above described the physical tightness test procedure used in this survey, a modification of a commercially available method. A field test for a single tank system[1] produced raw data which required analysis and interpretation before a determination could be made as to whether the test showed evidence that the tank system was leaking. Section 7 described the initial steps of data reduction which yielded a measured volume change rate and an estimate of the measurement variability of that rate for each tightness test. In that section, results of quality assurance retests were also given.

This section of the report discusses further statistical analyses required to evaluate the total measurement variability, to estimate the actual leak rate and to determine whether a given tank system can be judged to be tight or leaking, based on the tightness test. It also includes three further analyses. One speaks to the issue of whether the leaks measured by the test can be attributed to leaks in distribution lines. The second looks at how full tanks are kept in practice, which sheds some light on the relevance of assessing tank system leaks by filling tanks to capacity. The third discusses the possible impact of the typical filling behaviors reported on the estimates of percent of tank systems that leak in practice.

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[1] Due to the nature of the test, a "tank system leak" means a leak anywhere in the tank vessel, associated fill pipe, vent pipe, distribution lines, fittings, or connections.

I. TOTAL MEASUREMENT ERROR

The quality assurance retest data given in Section 7 offers a means of estimating the size of the error in the physical test measurement that is due to variation from one test occasion to another. It also indicates that the magnitude of this component of measurement error is substantially greater than the error measured for a single test result. In the usual statistical analysis of components of variance, the component measured for a single test result is the within-test variance, the component due to factors varying from test to test is the between-test variance, and their sum is the total variance of a single test result.

In order to estimate the total variance of a given test result, the average between-test variance must be estimated and added to the within-test variance estimated for that test. Two data sets were used to estimate the between-test variance: (a) the complete retest (34 cases) and (b) those test results from tanks which are clearly tight (observed volume change was a flow into the tank system of 0.0 to 0.2 gallons per hour, 133 cases). Data set (a) allows an estimate of total variability because both between-test and within-test components are involved in the test/retest but the underlying tank leak rate would not vary between test times. Data set (b) provides measures of leak which are due to random error alone. No liquid could actually flow into the tank during the test, since product in the tank was under test pressure. Thus, data set (b) also includes both components of variance. An estimate of total variance was computed from the measured volume changes in each data set, and the average within-test variance was estimated from the measured within-test variances for the same data sets. The between-test variance was then estimated by subtraction. Appendix D, Part V

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describes the estimation of between-test variance in more detail, specifying the model and formulas used.

The two sets of variance components estimates agreed very closely. In order to get a single estimate of between-test variance to use in adjusting the stated within-test variances, the two estimates were combined in a weighted average using the number of cases in the data set as the weights. The final estimate of between-test variance was 0.00199 gallons per hour squared, which in terms of gallons per hour is about 0.04 gallons per hour. (This figure has not been adjusted for test pressure as described below.) The estimated between-test variance was added to the square of each within-test standard error to get an estimated total measurement variance for each test result. The square root of this was then used as the total measurement standard error in the statistical hypothesis test described below.

II. ADJUSTING MEASURED LEAK RATES TO ACCOUNT FOR TEST PRESSURE

This subsection describes how leak rates were adjusted from test pressure to "typical" operating pressure (i.e., a set of standard assumed conditions) for tank systems judged to be leaking under test conditions. In order to conduct the physical test, increased hydrostatic pressure is placed on the tank system. As a consequence of this, any leak or flow through an orifice in the tank system would be increased over what would occur under the (smaller) pressure encountered in operation. Torricelli's form of Bernoulli's Law was used to calculate adjustments to the measured flow rates, under certain assumptions. It should be noted that the basis for the adjustment is the assumption that the measured flow represents a leak through an orifice or hole. Thus, it is not logically

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consistent to adjust test volume change rates for pressure unless the system, tank, or line was judged to be leaking, even though it would be computationally feasible to do so, and leak rate adjustments were made after the leak status had been determined.

Torricelli's and Bernoulli's Law assumes a flow is through an orifice with neither resistance nor turbulence. In our situation, this is not the case. The flow rates generally will be small enough so that the assumption of no turbulence is reasonable. However, in most cases, leaks will be through corroded sections and will be into soil which may present some resistance. The effect of resistance would be to lower the flow rate. How much the flow rate would be lowered under the different pressures is not known. Consequently, the effect of violation of these assumptions on the adjustment to leak rates is not known, but it is assumed to be negligible. There are some other implicit assumptions. These include that the orifice is constant, that the temperature and density do not change, and that the product is not viscous.

Since the test is conducted at elevated pressure, flow rates through any orifices will be larger under the test conditions than they would be under actual tank operation. The magnitude of the difference depends on a large number of variables. In particular, flow rates would vary by location of the hole in the tank (distance from the bottom), amount of fuel in the tank, and pressure of a water table part way up the tank. The adjustment factors would also vary with diameter of the tank. Since diesel tanks were tested at the same pressure (hence at a lower head-distance) as gasoline tanks, the adjustment also varies with fuel type because of the density difference. The assumed operating conditions used in calculating the adjustment factors (in addition to the basic assumptions of Bernoulli's law) are as follows:

- The water table is assumed to be below the bottom of the tank;
- The tank is assumed to be buried to the depth of three feet from grade to top of tank;
- Three tank diameters are assumed based upon volume, since actual diameter of tanks was not known);
- The average operating level of the tank is assumed to be half full; and
- The orifice or hole is assumed to be in the bottom of the tank.

The table below gives the adjustment factors used to adjust the estimated tank leak rates to these assumed standard operating conditions.

Adjustment factors for tank system leak rates

Tank diameter and associated volume ranges	Fuel type	
	Gasoline	Diesel
48" (0-1,100 gallons)	0.395	0.430
64" (1,101-7,000 gallons)	0.456	0.496
96" (7,001-15,000 gallons)	0.558	0.608

The factors were multiplied by the leak rates estimated by the physical tests to obtain the adjusted leak rates. The adjusted total measurement error is calculated by multiplying the total measurement standard error by the adjustment factor. Leaks measured by the line tests can be similarly adjusted either to the system test pressure or to assumed operating conditions. As is discussed in Section V below, valid distribution line tests could not be conducted on about 60 percent of the tank systems judged to be leaking. Further, distribution line leak rates accounted for very little of the system leak rate. Thus for the major findings in this report, system leak rates were adjusted directly to assumed operating conditions. See Part VII of Appendix D for details.

III. DETERMINATION OF LEAK STATUS

The physical leak measurement technique was described in Section 6. As a result of variability in the instrument readings and temperature adjustment process, the physical test does not produce an absolutely positive determination that a tank system either is leaking or is not leaking.[2] Instead, the test produces an estimated leak rate (or flow rate) along with a measure of uncertainty in the estimate (i.e., standard deviation of the leak rate).[3] The determination that a tank system is "leaking" is, therefore, a statistical judgment. The approach taken to leak status determination in this report is the statistical hypothesis testing model. The condition of "non-leaking" is represented by the hypothesis of a zero leak rate. The condition of leaking can then be stated as "having a measured leak rate that is significantly different from zero (flowing out of the tank system)."

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[2] In common practice, a tank is certified or not based on comparing the observed volume change rate to the NFPA standard of 0.05 gallons per hour.

[3] In some cases, the tank system test produced data that were judged to be unreliable. These are considered inconclusive results, by any decision rule. In other cases, unquantifiably large leaks were encountered. These are judged to be leaks by every decision rule.

The ideal statistical test should have:

- A low probability of false alarm (i.e., for non-leaking tank systems, have a low probability of falsely calling the tank system leaking. This probability is also known as the significance level); and
- Have a low probability of failing to detect a real leak. (This probability is one minus the power of the test.)

The probability of failing to detect a real leak depends on three factors: the size of the total measurement error of the tank system test, the size of the "real leak" one wishes to detect, and the probability of false alarm for the statistical test adopted. Recognizing the inherent conflict between objectives (a) and (b), above, we have considered two statistical tests with the attributes shown below:

	Probability of a false alarm for a tight tank system	Probability of failing to detect a leak of 0.10 gallons per hour[1] or more
Test 1	5 percent	5 percent
Test 2	1 percent	16 percent

[1] A true leak (i.e., adjusted for test pressure) of 0.10 gallons per hour would have the stated probability of detection on average, since the average adjusted total standard error is 0.030 gallons per hour.

We have selected Test 1 as the approach used in this study because it provides a low probability of a false alarm and provides an equally low chance of failing to detect a leak of 0.10 gallons per hour when one really exists. The null hypothesis was that the true leak rate is zero, and the alternative hypothesis was that there is a leak out of the tank. The test statistic was the observed volume change rate divided by its standard error. The null hypothesis was tested at a 5 percent significance level by comparing the test statistic to 1.645. If the test statistic was greater than this value, which is taken from the normal distribution, the tank was judged to be leaking. Table 8-1 shows the resulting estimates for percentage of tank systems leaking in the United States (35 percent using Test 1; 32 percent using Test 2). Note that the leak status determination is made before adjusting the leak rate to operating conditions for tank systems judged to be leaking by the statistical test.

Although the probability of failing to detect a leak of a given size (one minus the power) is reported on average for the statistical test used in the report, it is not guaranteed for each tank system tested. One way of specifying this probability as well as the probability of false alarm (significance level) is to run a second test which declares a tank system not leaking only if its measured flow rate is significantly greater than would be consistent with a stated actual leak rate. The final decision for a given tank system test would be inconclusive if the two statistical tests disagreed. Applying this approach with a five percent (or less) probability of failing to detect a leak of 0.10 gallons per hour (on an adjusted basis) or more does not noticeably change the results. The same tank systems are judged to be leaking as were under Test 1 above, and a few of the tank systems judged not leaking by Test 1 become inconclusive after applying the second rule (six cases in the raw data). The percent judged leaking calculated from this slightly reduced base remains 35 percent when rounded to the nearest percent. Thus the stated probability of failing to detect a fairly large leak does hold for most actual tests.

Table 8-1. Estimated percentage of underground motor fuel storage tank systems judged to be leaking under test conditions in the U.S., business and government sectors, using statistical tests

Leak status of tank system[1]	Test 1 (P_1 = .05 P_2 = .05)[2]	Test 2 (P_1 = .01 P_2 = .16)[2]
Percent judged to be leaking under test conditions[3]	35%	32%
Percent judged to be not leaking under test conditions	65%	68%

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[1] Under both tests, 5.5 percent of tanks tested had an inconclusive result. This includes cases where the data were judged unreliable and cases with a statistically significant measured inflow, indicating a vapor pocket or other problem with the test. They are not included in the base on which the percentages are figured.

[2] P_1 = Probability of a false alarm (i.e., falsely declaring a tight tank as leaking) on any one test.

P_2 = Probability of failing to detect a leak of 0.10 gallons per hour when one exists, using a value of 0.03 as the standard deviation of leak rate (the average adjusted total standard deviation)

[3] Includes cases with unquantifiably large leaks as well as with statistically significant leaks.

As a final comparison, we have looked at the estimate of percentage of leaking tank systems that would have resulted if we had used the 0.05 gallons per hour National Fire Protection Association criterion[4] (or "cut-off") as the critical value to distinguish tight or certifiable tank systems from not certifiable (leaking) tank systems. Although this is not a statistical test for detecting non-zero leak rates, it is included for comparison since many commercial tank testing companies apply this criterion, although they use various field test equipment and procedures. Results of applying this criterion are shown in Table 8-2. Applying the .05 gallons per hour cut-off to the estimated leak rates at test conditions results in an estimate of 42 percent of tank systems leaking. Adjusting the leak rates for these tank systems downwards to compensate for the pressure used in the test, as described in Section 8-II above, and applying the .05 gallons per hour cut-off to the adjusted leak rates results in 33 percent of tank systems leaking (because 21 percent of the leak rates initially greater than 0.05 gallons per hour were reduced to less than 0.05 gallons per hour as a result of the pressure adjustment).

These results are given solely as illustrative of what might be found if a national certification program were conducted. Each testing company conducts its tests under different pressures and with different sensitivities. The cut-off is then applied to the observed volume change rate without any pressure adjustment. The results using the NFPA criterion show a large fraction of the underground motor fuel storage tank systems in the United States to be leaking, even though the NFPA test ignores leaks below the

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[4] ANSI/NFPA 329, "Recommended Practices for Handling Leakage of Flammable and Combustible Liquids," Section 4-3.10.1, 1983.

Table 8-2. Estimated percentage of underground motor fuel storage tank systems judged to be leaking under test conditions in the U.S., business and government sectors, based on NFPA .05 gallons per hour criterion

	Using NFPA .05 gallons per hour criterion	
Leak status of tank systems[1]	At test pressures[2]	Adjusted to typical operating conditions[3]
Percent judged to be leaking under test conditions[4]	42%	33%
Percent judged to be not leaking under test conditions	58%	67%

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[1] In both columns, 6.4 percent of tanks tested had an inconclusive result. This includes cases where the data were judged unreliable and cases with a measured inflow of greater than 0.05 gallons per hour, indicating a vapor pocket or other problem with the test. These cases are not included in the base on which the percentages are figured.

[2] The test procedure resulted in a small pressure, 4 psi, at the bottom of the tank.

[3] Leak rates were adjusted to typical operating conditions only for those tank systems initially judged to be leaking.

[4] Includes cases with unquantifiably large leaks as well as with measured leak rates greater than 0.05 gallons per hour.

arbitrary 0.05 gallons per hour and does not examine the estimated leak rate relative to its standard error.

In summary, this report uses a statistical test to distinguish leaking and tight tank systems. The test has a five percent probability of false alarm, while running on average a five percent risk of failing to detect leaks of 0.10 gallons per hour or larger. Furthermore, the use of other statistical test criteria described above would not substantially alter the overall results.

IV. ASSESSING THE UTILITY OF TESTING FOR LEAKAGE BY FILLING TANKS TO CAPACITY

When tank systems were tested for leaks, the process involved filling the tank to capacity and then observing the resulting leak rates, if any. A concern arising from this approach is the extent to which this procedure reflects the general status of tank storage. For example, if it is the case that tanks are seldom filled to capacity, the discovery of leaks in the tops of tanks using the specified testing procedure does not provide information with general application to real world situations. On the other hand, if tanks are filled to capacity or near-capacity routinely, the testing procedures are appropriate.

In order to assess the extent to which tanks are utilized in their full capacity, an analysis of the average proportion of each tank utilized before and after delivery of a motor fuel for storage (as reported by tank owner/operators in the questionnaire) was undertaken for the nearly 2,300 cases on which such data was available. Just before delivery, the median average proportion of a tank utilized was 20 percent, with the

75th percentile being 33.3 percent and the 25th percentile at 10 percent. The most frequent or modal value is 25 percent. Thus, on average, the product stored within tanks is allowed to drop to a rather low level before delivery of a further supply. After delivery, the median average proportion of the tanks' capacities utilized jumped to 83.3 percent, with the 75th percentile at 97.5 percent and the 25th percentile at 62.7 percent. Thus, 25 percent of the tanks were filled over 97.5 percent full. The most frequent or modal value was 100 percent.

Respondents were also asked the largest amount their tank was ever filled. Responses to this question had a median value of 100 percent. The 25th percentile was 92 percent full. Thus, the majority of tanks are filled to capacity at some time, and most tanks have filled nearly to capacity.

Such sample estimates suggest that a substantial number of the tanks surveyed routinely utilized all or most of their storage capacity, consequently exposing virtually all of a tank's surface area to the possibility of being a potential source of a leak. It is therefore reasonable to employ a testing procedure which involved filling a tank to capacity in an effort to detect possible sources of leakage.

V. ASSESSING THE CONTRIBUTION OF DISTRIBUTION LINE LEAKS TO MEASURED TANK SYSTEM LEAKS

A. Comparison of Leaking Tanks with Valid Distribution Line Tests With Those Whose Distribution Lines Were Not Tested

In assessing the potential proportion of measured tank system leaks[5] which might be attributed to distribution line leaks, a subset of our representative sample of tank systems was analyzed. This subset was first restricted to single tank systems judged to be leaking and with quantified leak rates, of which there are 110 in the data set. Although distribution line tests were attempted for all tested tanks, such tests often failed due to bad check valves, bleed-back or other problems (see Section 6). Thus, valid distribution line tests with quantified leak rates were available for only 43 of the 110 quantified leaking tank systems. Before analyzing the data obtained from the completed valid distribution line leak tests, it is important to consider the issue of the extent to which they may differ from tanks where valid distribution line test results were not obtained. For example, is there evidence that the ability to complete valid distribution line tests was linked to the type of fuel stored in the tanks, the material used in the construction of the tanks, etc? Cross-tabulations comparing the distributions of those leaking tank systems with valid line leak data and those without across categories of variables with potential impact were examined in conjunction with tests of association, such as the chi-square test, where appropriate.

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[5] Recall that a "tank system leak" refers to a determination of a leak based on the physical test. The leak could actually be in the tank vessel or any of the associated lines, pipes, or fittings.

Variables for which there was evidence of a difference in the distribution between those leaking tank systems with completed valid tests and those without included: type of establishment (government sites had a higher than expected valid completion rate), material of construction (fiberglass had a lower than expected valid completion rate), and type of delivery system (pressure pumps had a lower than expected valid completion rate). Comparisons between the group with valid data and that without on the actual measure of leak rate indicated no significant differences between their average values, although the leak rates for those tank systems with incomplete tests were significantly more variable than those without.

B. Consideration of Distribution Line Leakage as a Proportion of Total Measured Leakage

The finding of a leak during testing can be attributed to a distribution line leak, a vessel leak, both, or some other leak(e.g., fill pipe, vent pipe, manway fitting, etc.) For the 43 cases known to have leaks and for which valid distribution line leak data was obtained, an examination of the proportion of each total measured leak attributable to a distribution line leak was undertaken. In doing this, it was necessary to adjust the line leak rate values to the system test pressure, taking account of differences in tank diameters and the type of pump used (suction or pressure). (Appendix D, Part VI, described this adjustment.)

Of the 43 cases, in only one case (2.3%) was the proportion of the system leakage attributable to the distribution line more than 25 percent. In fact, leakage in the distribution line accounted for less than 10 percent of the leakage for 38 of the

43 cases (88.4% of the cases) and for less than two percent of the measured leakage for 23 of the 43 cases (53.5% of the cases). Thus, at least for those cases in which valid leak rate measurements could be obtained, leaks in the distribution lines account for very little of the total measured leakage.

VI. PERCENT OF TANK SYSTEMS LEAKING UNDER OPERATING CONDITIONS

Certain features of the tank testing method are different from typical operating conditions, especially the overfilling of the tank during the test.

It is certainly reasonable to ask whether some of the leaks detected under test conditions might have been due to holes near the top of the tank above normal fill levels. Data from the survey reveal that it is common practice to fill tanks to 100 percent capacity when product is delivered. In fact, 100 percent was the modal value for this variable, and the median of the reported average fill level was 83 percent of capacity. Thus, the data suggest that even holes near the top of the tanks would be subject to leaking, at least just after product delivery.

On the other hand, the average tank fill level just prior to delivery had a median value of about 20 percent of tank capacity. Therefore, as a rough approximation, a typical operating level might be midway between the high and low point, or 52 percent of capacity. If one were to further assume that holes were evenly distributed between the top and bottom of the tank, then an estimated 52 percent x 35 percent = 18 percent of the tank systems would be leaking on the average at any point in time under typical fill level conditions.[6] Furthermore, using average percent filled after delivery may be a conservative estimate of operational fill levels. When asked about the maximum gallons ever stored, most respondents reported 100 percent, and only one-quarter were below 92 percent full.

In summary, if we are willing to assume that holes are uniformly distributed around the tank circumference (We have no data to verify this assumption.), we could calculate that:

- Approximately 35 percent of the tank systems would be leaking if they were filled to capacity;
- If all tanks are ever filled to capacity during the year, then an estimated 35 percent of the tank systems in the country are leaking at one time or another during a year;
- Approximately 29 percent (.35 x .83) of tank systems are leaking just after the time of product delivery the way tanks are normally filled; and
- Approximately 18 percent (.35 x .52) of the tanks are leaking at a random point in time.

Because of the nature of the test procedures used (i.e., overfilled tanks), we might be concerned about the possibility that a large portion of the leaks could be near the top of the tank and its associated pipe fittings. If that were the case, test results in this study could overstate the percentage of tanks leaking under operating conditions. While we do not have information in our study on the location of the leaks, an American Petroleum Institute report (API letter of March 27, 1981 from F.B. Killmar to Mr. Paul J. Sausville, P.E. Chief, Northeast Sector Wastewater Management Bureau, New York State Department of Environmental Conservation) provides some relevant statistics. This API report found that among all 318 leaking tanks, only 4.4 percent had leaks limited to the upper one-third of the tank. Even though the API study was based on volunteer reports from leaking tank inspections rather than a representative probability sample, these findings seem to strongly dispel any concern that leaks are predominantly or disproportionately close to the top of the tank. As a result, the 18 percent estimate given above for percentage of tanks leaking at a random point in time under operating conditions may be an underestimate.

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[6] This is a rough approximation which could be refined by calculating highest and lowest fill levels for each tank separately, and then computing the median and mean fill levels as fuel is withdrawn. Fuel withdrawal rate could be assumed as uniform over time or simulated from inventory data. Finally, refinements could be made to account for the fact that the assumption of uniform leak distribution over the surface of the tank is not identical to uniform leak distribution over volume. However, since actual leak distribution is unknown, such refinements do not seem warranted at present.

SECTION 9

STATISTICAL ANALYSIS

I. NATIONAL ESTIMATES OF THE NUMBERS OF UNDERGROUND MOTOR FUEL STORAGE TANKS AND ESTABLISHMENTS WITH UNDERGROUND MOTOR FUEL STORAGE TANKS

In the continental United States (i.e., excluding Alaska, Hawaii, and the trust territories) there are an estimated 796,000 underground tanks currently being used for the storage of motor fuel at an estimated 326,000 business, government and farm establishments. Table 9-1 shows the estimated number of tanks and establishments with tanks (as well as the mean and median number of tanks per establishment) overall and within the business/government stratum and the farm stratum. Overall there are an average of 2.4 tanks per establishment with such tanks, and a median of three tanks per establishment.

Among the business and government establishments (based on analysis of the combined fuel establishment and large establishment strata), there are an estimated 638,000 underground motor fuel storage tanks in use at approximately 247,000 establishments. The average number of tanks per establishment for the business and government sample is 2.6 tanks. The median number of tanks per establishment is three. (The sample strata are described in detail in Section 4 of this report.)

According to survey estimates, there are approximately 158,000 underground motor fuel storage tanks in use on about 79,000 farms, or an average of 2.0 tanks per farm with underground motor fuel storage tanks. The median number of tanks

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Table 9-1. Estimates of the number of underground motor fuel storage tanks and the number of establishments with underground motor fuel storage tanks in the continental United States (95% confidence bounds in parentheses)

Type of establishment	Number of establishments with tanks (1,000's)	Number of tanks (1,000's)	Number of tanks per establishment with tanks	
			Mean	Median
Business & government	247 (220-275)	638 (584-692)	2.6 (2.4-2.8)	3 -
Farms	79 (58-100)	158 (< 453)	2.0 (< 5.0)	1 -
Total	326 (296-356)	796 (503-1,090)	2.4 (1.6-3.2)	3 -

per farm is one tank. Because of the small sample size for farms, the resultant large sampling weights, and the associated broader confidence bounds, the farm sample was not combined with the samples of fuel and large establishments in the succeeding analyses. For a detailed discussion of the farm sample, see Appendix G of this report.

A. Estimates by Survey Region of the Number of Underground Motor Fuel Storage Tanks and Establishments

The survey sample was stratified to provide estimates for six predefined survey regions. Table 9-2 lists the six survey regions and shows the estimated number of tanks and establishments with tanks, plus the mean and median number of tanks per establishment, within each of the regions. The Northeast survey region has the highest estimated number of tanks (186,000) and establishments (69,000). The survey region with the smallest number of tanks is the Mountain region, with an estimated 36,000 tanks at 14,000 establishments. The average number of tanks per establishment is 2.6 tanks, and ranged from a high of 2.7 tanks per establishment in the Northeast to a low of 2.3 tanks per establishment for the central region. The median number of tanks per establishment for all regions combined is three. The Northeast, Mountain, and Pacific survey regions each have a median of two tanks per establishment. In the Southeast, Midwest, and Central survey regions the median number of tanks per establishment is three.

Table 9-3 displays the estimates of the number of underground motor fuel storage tanks and establishments with motor fuel

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Table 9-2. Estimates, by survey region, of the number(1) of underground motor fuel storage tanks and the number of establishments with underground motor fuel storage tanks in the continental United States (95% confidence bounds in parentheses)

Survey region	Number of establishments with tanks (1,000's)	Number of tanks (1,000's)	Number of tanks per establishment with tanks	
			Mean	Median
1 Northeast	69 (52-86)	186 (175-198)	2.7 (2.1-3.3)	2 -
2 Southeast	48 (39-58)	126 (106-147)	2.6 (2.4-2.8)	3 -
3 Midwest	53 (39-67)	139 (108-170)	2.6 (2.4-2.9)	3 -
4 Central	27 (15-39)	63 (43-84)	2.3 (2.0-2.6)	3 -
5 Mountain	14 (12-17)	36 (23-49)	2.5 (2.1-2.9)	2 -
6 Pacific	35 (29-42)	87 (58-116)	2.4 (2.0-2.9)	2 -
Total	247 (220-275)	638 (584-692)	2.6 (2.4-2.8)	3 -

(1) Does not include farms or tanks at farms.

Table 9-3. Estimates, by type of establishment, of the number[1] of underground motor fuel storage tanks and the number of establishments with underground motor fuel storage tanks in the continental United States (95% confidence bounds in parentheses)

Type of establishment	Number of establishments with tanks (1,000's)	Number of tanks (1,000's)	Number of tanks per establishment with tanks	
			Mean	Median
Government and military	45 (29-62)	98 (69-128)	2.2 (1.8-2.5)	2 -
Gas stations owned by major petroleum companies	33 (26-41)	118 (87-148)	3.6 (3.3-3.8)	3 -
Gas stations owned by other companies	58 (50-67)	204 (174-233)	3.5 (3.2-3.8)	3 -
Other fuel-related establishments	36 (30-43)	77 (64-90)	2.1 (1.8-2.4)	2 -
Large non fuel-related estabments (with ≥ 20 employees)	74 (55-93)	142 (97-187)	1.9 (1.6-2.2)	2 -
Total	247 (220-275)	638 (584-692)	2.6 (2.4-2.8)	3 -

[1] Does not include farms or tanks at farms.

storage tanks as they are distributed by type of establishment. Establishment types include:

- Government and military establishments, including state, local and federal facilities;
- Gas stations (SIC code 5541) owned and/or operated by major petroleum companies (according to the establishment manager);
- Gas stations (SIC code 5541) owned by other companies;
- Other fuel-related establishments (i.e., transportation related industries); and
- Large non-fuel-related establishments (with 20 or more employees).

Gasoline stations without regard to ownership account for about half (321,000) of all tanks. but a little over a third (92,000) of the total number of establishments with tanks. Of the five establishment types, gasoline stations owned by other (i.e., non-major) companies account for the largest number of tanks (203,000). The other fuel-related establishments have the smallest share of tanks (an estimated 77,000) and establishments (an estimated 36,000). The large non-fuel-related establishments category has the highest estimated number of establishments with tanks (74,000 establishments), and has second highest estimated number of tanks (142,000). The average number of tanks per establishment, which is 2.6 for establishments of all types, ranges from a high of 3.6 for gas stations owned by major petroleum companies, to a low of 1.9 for the large non-fuel-related establishments. The median number of tanks per establishment is three for both of the categories of gas stations, and two for the non-gas station categories.

II. CHARACTERISTICS OF ESTABLISHMENTS WITH UNDERGROUND MOTOR FUEL STORAGE TANKS

There are an estimated 247,000 government and business establishments that use underground tanks to store motor fuel. Table 9-4 displays the estimated number, the 95 percent confidence bounds for the estimates, and the percentage distribution of the type of establishment, within region. The differences in the distribution of establishment types within the survey regions are described in Section 9.II.A. In addition, specific establishment characteristics were analyzed by region and establishment type, and are displayed in Tables 9-5 and 9-6. These tables are discussed in Section 9.II.B.

A. Distribution of Types of Establishments within Survey Region

The distribution of establishment types is relatively similar across the six survey regions, although there are some differences, particularly in gas station ownership type in certain regions. While gas stations owned by major petroleum companies account for 13 percent of the establishments across all regions, 23 percent of the establishments in the Pacific region were gas stations owned by major petroleum companies. In contrast, the lowest proportion of gas station establishments owned by major petroleum companies (8%) occurs in the mountain regions. Gas stations owned by other companies (i.e., not owned by major petroleum companies) account for 24 percent of the establishments in all survey regions, but for only 11 percent of the establishments in the Pacific survey region. The Midwest survey region has the highest proportion (29%) of gas stations owned by other companies.

Table 9-4. Estimates of the number and percent of establishments with underground motor fuel storage tanks(1) across establishment types for the six survey regions(2) (95% confidence bounds on number of establishments in parentheses)

Survey region	Government and military establishments	Gas stations owned by major petroleum companies	Gas stations owned by other companies	Other fuel-related establishments	Large non-fuel-related establishments	Total
Northeast						
Number:	13,000	7,000	17,000	11,000	21,000	69,000
% in region:	19%	10%	24%	16%	31%	100%
95% conf. bounds:	(< 27,000)	(3,000-11,000)	(13,000-20,000)	(6,000-16,000)	(13,000-29,000)	(52,000-86,000)
Southeast						
Number:	7,000	7,000	11,000	6,000	17,000	48,000
% in region:	15%	15%	23%	12%	35%	100%
95% conf. bounds:	(2,000-13,000)	(4,000-11,000)	(9,000-14,000)	(4,000-8,000)	(5,000-28,000)	(39,000-58,000
Midwest						
Number:	10,000	7,000	16,000	8,000	12,000	53,000
% in region:	19%	14%	29%	15%	23%	100%
95% conf. bounds:	(6,000-15,000)	(3,000-12,000)	(12,000-20,000)	(4,000-12,000)	(4,000-29,000)	(39,000-67,000)
Central						
Number:	6,000	3,000	7,000	4,000	7,000	27,000
% in region:	24%	11%	25%	15%	29%	100%
95% conf. bounds:	(4,000-9,000)	(1,000-5,000)	(4,000-10,000)	(3,000-5,000)	(< 15,000)	(15,000-39,000)
Mountain						
Number:	3,000	1,000	4,000	2,000	4,000	14,000
% in region:	20%	8%	28%	15%	29%	100%
95% conf. bounds:	(2,000-3,000)	(< 3,000)	(1,000-7,000)	(1,000-3,000)	(3,000-5,000)	(12,000-17,000)
Pacific						
Number:	5,000	8,000	4,000	6,000	12,000	35,000
% in region:	15%	23%	11%	16%	35%	100%
95% conf. bounds:	(2,000-9,000)	(6,000-10,000)	(0-8,000)	(5,000-6,000)	(7,000-19,000)	(29,000-42,000)
All survey regions						
Number:	45,000	33,000	58,000	36,000	74,000	247,000
% all regions:	18%	13%	24%	15%	30%	100%
95% conf. bounds:	(29,000-62,000)	(26,000-41,000)	(50,000-67,000)	(30,000-43,000)	(55,000-93,000)	(220,000-275,000)

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(1) Does not include farms.
(2) Percents are calculated prior to rounding.

The Central region has the highest proportion of government and military establishments, with 24 percent compared to 18 percent for all regions. The Midwest survey region has a slightly lower percentage of large non-fuel-related establishments, with 23 percent compared to 30 percent for all regions. The proportion of other fuel related establishments is nearly identical across regions.

B. Selected Establishment Characteristics, Analyzed by Region and by Establishment Type

Selected establishment characteristics were analyzed by region and by establishment type for the establishments with underground motor fuel storage tanks. These analyses were based on a file of 876 establishments, weighted to represent 247,000 establishments. The percent of establishments exhibiting each of the selected characteristics is displayed in Table 9-5 (by region) and Table 9-6 (by establishment type).

1. Establishments with Underground Waste Oil Tanks

Overall, 31 percent of the establishments have underground waste oil tanks on site. Most owner/operators knew whether or not their establishments have waste oil tanks (over 99%). The Central and Southeast regions have the smallest percentage of establishments with underground waste oil tanks (24% and 25% respectively) and the Pacific region has the largest percentage (43%). Among establishment types, gas stations of both types have higher percentages of underground waste oil tanks than other establishment types. More than half (59%) of the gas stations

Table 9-5 Estimates, by survey region, of the percent of establishments with underground motor fuel storage tanks(1) with selected characteristics (95% confidence bounds in parentheses)

Survey region	Percent of establishments with waste oil tanks	Percent of establishments with abandoned tanks	Percent of establishments where clean sand or pearock used as backfill	Percent of establishments required to have tank installation permits	Percent of establishments required to have tank operating licenses	Percent of establishments with insurance to cover sudden motor fuel spills	Percent of establishments with insurance to cover non-sudden motor fuel spills
1 Northeast	30% (21-39%)	11% (7-16%)	82% (75-89%)	59% (19-98%)	25% (2-48%)	80% (68-92%)	63% (47-79%)
2 Southeast	25% (20-29%)	15% (8-22%)	78% (65-91%)	49% (45-53%)	22% (16-28%)	79% (69-90%)	64% (59-69%)
3 Midwest	32% (28-38%)	16% (7-25%)	88% (75-100%)	52% (34-69%)	31% (17-34%)	75% (63-87%)	65% (56-74%)
4 Central	24% (10-38%)	17% (4-30%)	63% (54-70%)	37% (11-64%)	15% (3-26%)	73% (52-94%)	63% (41-86%)
5 Mountain	32% (22-42%)	15% (5-25%)	72% (53-90%)	62% (40-84%)	34% (14-53%)	96% (96-97%)	94% (88-99%)
6 Pacific	43% (29-58%)	9% (6-12%)	65% (52-77%)	78% (63-94%)	49% (35-62%)	92% (87-98%)	89% (81-98%)
Total	31% (27-35%)	14% (11-17%)	78% (73-83%)	56% (44-69%)	29% (21-37%)	81% (76-86%)	69% (64-75%)

(1)Does not include farms.

Table 9-6. Estimates, by establishment type, of the percent of establishments with underground motor fuel storage tanks[1] with selected characteristics (95% confidence bounds in parentheses)

Type of establishment	Percent of establishments with waste oil tanks	Percent of establishments with abandoned tanks	Percent of establishments where clean sand or pearock used as backfill	Percent of establishments required to have tank installation permits	Percent of establishments required to have tank operating licenses	Percent of establishments with insurance to cover sudden motor fuel spills	Percent of establishments with insurance to cover non-sudden motor fuel spills
Government and military	17% (11-23%)	11% (6-16%)	76% (70-82%)	33% (18-47%)	11% (3-20%)	70% (59-81%)	65% (54-77%)
Gas stations owned by major petroleum companies	59% (47-67%)	4% (1-7%)	92% (86-99%)	87% (75-99%)	55% (47-62%)	78% (69-86%)	70% (60-81%)
Gas stations owned by other companies	46% (38-54%)	22% (16-29%)	89% (84-93%)	61% (44-76%)	36% (24-48%)	84% (79-89%)	65% (55-75%)
Other fuel-related establishments	29% (23-36%)	13% (8-17%)	76% (68-85%)	60% (43-76%)	32% (20-44%)	80% (73-87%)	73% (67-80%)
Large non fuel-related establishments	16% (6-26%)	14% (6-21%)	66% (51-80%)	59% (42-75%)	20% (6-33%)	88% (80-95%)	73% (65-81%)
Total	31% (27-35%)	14% (11-17%)	78% (73-83%)	56% (44-69%)	29% (21-37%)	81% (76-86%)	69% (64-75%)

[1] Does not include farms.

owned by major petroleum companies have underground waste oil tanks, and 46 percent of the gas stations owned by other companies have underground waste oil tanks. Government and military establishments and large non-fuel-related establishments have the smallest percentage of establishments with underground waste oil tanks, with 17 percent and 16 percent respectively.

Approximately 98 percent of the establishments that have underground waste oil tanks have only one of these tanks. Altogether, there are an estimated 78,000 underground waste oil tanks at establishments that also have underground motor fuel tanks. (This estimate does not include waste oil tanks that may be at establishments that do not have underground motor fuel storage tanks, since those establishments were not surveyed.)

2. Establishments with Abandoned Underground Tanks

Approximately 14 percent of the establishments that have in-use underground motor fuel storage tanks also have one or more tanks on site that have been abandoned (i.e., are no longer in use, and have not been removed.) Again, most owner/operators (95%) knew whether their establishment had such a tank on site. Across regions the percentages of establishments with abandoned tanks is similar, ranging from a high of 17 percent in the Central region to a low of 9 percent in the Pacific region. A more striking difference can be seen in the percentages of establishments with abandoned tanks across establishment types. Only 4 percent of the gas stations owned by major petroleum companies have abandoned tanks, while 22 percent of the gas stations owned by other companies have abandoned tanks.

Nearly 70 percent of the establishments with in-use motor fuel tanks that have abandoned underground tanks have only one abandoned tank, but the number of abandoned tanks in the survey sample ranges from one tank to ten tanks per establishment. Overall, there are an estimated 53,000 abandoned underground tanks at establishments that have in-use underground motor fuel storage tanks. (Note that the estimates provided in this section are based only on establishments with in-use underground motor fuel storage tanks. The numbers and percentages given here do not include abandoned tanks at establishments that do not have in-use underground motor fuel storage tanks.)

3. Establishments with Clean Sand or Gravel as Tank Backfill

Overall, 78 percent of the establishments claim to have used clean sand, pearock or peagravel for backfill around their tanks. (This estimate is based on the three-quarters [74%] of owner/operators who knew the backfill material.) The remaining 22 percent used excavation soil, rubble, clay and combinations including these materials to fill around their tanks. In the Central and Pacific regions a lower percentage of establishments used the clean sand/clean gravel backfill (63% and 65% respectively), while in the Midwest the percentage using this type of backfill was higher (88%). A higher percentage of both types of gas stations used clean sand/clean gravel backfill. Among gas stations owned by major petroleum companies, 92 percent used clean sand/clean gravel as backfill, while among gas stations owned by other companies 89 percent used this type of backfill. Only 66 percent of the large establishments used clean sand/clean gravel as backfill.

4. Establishments Required to Have Tank Installation Permits

Operators of 56 percent of the establishments with underground motor fuel storage tanks did not know whether the establishment was required to obtain a permit for the installation of the underground tanks. Among those who did know, 56 percent said they were required to obtain such a permit. The Central region has the lowest percentage of establishments reporting a required installation permit (37%) while the Pacific region has the highest percentage (78%). Among gas stations owned by major petroleum companies, where this question was answered, 87 percent said they were required to have installation permits. However, among government and military establishments, where this question was answered, the owner/operators said an installation permit was required for only 33 percent of the establishments.

5. Establishments Required to Have Tank Operating Licenses

Whether the establishment was required to have an operating license was known by 84 percent of responding owner/operators. At these establishments, only 29 percent of the establishments overall are required to have tank operating licenses, according to the establishment operators. Differences in the proportions of establishments required to have licenses are noticeable across survey regions and establishment types in patterns similar to the differences in percentages of establishments required to have installation permits. Again the Pacific survey region has the highest percentage of establishments requiring licenses (49%, or two thirds more that the overall percentage), and the Central survey region has the lowest (15%, or about half of the overall percentage.) Only 11 percent of the government and military establishments are required to have operating licenses, while 55 percent of the gas stations owned by major petroleum companies have such licenses.

6. Establishments with Insurance Coverage for Sudden Motor Fuel Spills

Among all regions and establishment types, 81 percent of establishment operators who answered this question believe they have insurance to cover damage to people or property caused by sudden motor fuel spills. Most (85%) did answer the questionnaire item. The Mountain region has the highest percentage of establishments with sudden spill coverage, with 96 percent of the establishment operators claiming to have this type of coverage, closely followed by the Pacific region, with 92 percent of the establishment operators claiming to have this type of coverage. Among the five establishment types, government and military have the lowest percentage of establishments covered for sudden spills (70%) and large non-fuel-related establishments have the highest percentage covered, with 88 percent of the establishment operators claiming to have this type of coverage.

7. Establishments with Insurance Coverage for Non-sudden Motor Fuel Spills (Including Leaks)

A total of 69 percent of the establishment operators who answered this item believe that their establishments have insurance to cover damage to people and property caused by non-sudden spills of motor fuel (such as tank system leaks). (Since this type of insurance coverage is not yet common, this belief may be unfounded.) A slightly lower number (78%) answered this item than answered the "sudden spills" question. A higher percentage of the operators in the Mountain and Pacific regions believe that their establishments are covered by insurance for non-sudden motor fuel spills (94% in the Mountain region and 89% in the Pacific region). There was very little difference in the percentage of operators claiming non-sudden spill coverage across establishment types.

III. CHARACTERISTICS OF UNDERGROUND MOTOR FUEL STORAGE TANKS

There are an estimated 638,000 underground motor fuel storage tanks at business and government establishments in the continental United States. Table 9-7 shows the numerical and percent distribution of these tanks by survey region and establishment type. The differences in these distributions across survey region are described in Section 9.III.A below. Selected tank characteristics, including tank age, tank capacity, products held in the tank, and various installation characteristics, were also analyzed by survey region and by establishment type. The results of these analyses are reported in Tables 9-8 through 9-15, and are discussed in Section 9.III.B.

A. Distribution of Tanks by Type of Establishment within Survey Region

As is shown in Table 9-7, tanks at government and military establishments account for 15 percent of all of the underground motor fuel tanks. This proportion is about the same across all

Table 9-7. Estimates of the number and percent of underground motor fuel storage tanks[1] across establishment types for the six survey regions[2] (95% confidence bounds on number of establishments in parentheses)

Survey region	Tanks at government and military establishments	Tanks at gas stations owned by major petroleum companies	Tanks at gas stations owned by other companies	Tanks at other fuel-related establishments	Tanks at large non-fuel-related establishments	Total
Northeast						
Number:	25,000	29,000	61,000	27,000	44,000	187,000
% in region:	14%	16%	33%	14%	24%	100%
95% conf. bounds:	(2,000-49,000)	(9,000-50,000)	(48,000-74,000)	(18,000-35,000)	(20,000-68,000)	(175,000-198,000)
Southeast						
Number:	17,000	24,000	40,000	12,000	33,000	126,000
% in region:	14%	19%	32%	9%	26%	100%
95% conf. bounds:	(9,000-25,000)	(12,000-37,000)	(31,000-50,000)	(6,000-17,000)	(14,000-52,000)	(106,000-147,000)
Midwest						
Number:	26,000	25,000	52,000	16,000	20,000	139,000
% in region:	19%	14%	29%	15%	23%	100%
95% conf. bounds:	(14,000-37,000)	(9,000-40,000)	(39,000-65,000)	(9,000-24,000)	(2,000-39,000)	(108,000-170,000)
Central						
Number:	13,000	10,000	23,000	9,000	9,000	63,000
% in region:	20%	15%	37%	14%	14%	100%
95% conf. bounds:	(8,000-18,000)	(4,000-15,000)	(11,000-36,000)	(7,000-10,000)	(< 19,000)	(43,000-84,000)
Mountain						
Number:	7,000	4,000	13,000	5,000	7,000	36,000
% in region:	20%	11%	36%	13%	20%	100%
95% conf. bounds:	(3,000-11,000)	(< 11.000)	(2,000-24,000)	(4,000-6,000)	(3,000-11,000)	(23,000-49,000)
Pacific						
Number:	10,000	26,000	14,000	8,000	28,000	87,000
% in region:	12%	29%	16%	10%	33%	100%
95% conf. bounds:	(2,000-19,000)	(20,000-31,000)	(1,000-27,000)	(7,000-10,000)	(3,000-53,000)	(58,000-116,000)
All survey regions						
Number:	98,000	118,000	204,000	77,000	142,000	638,000
% all regions:	15%	18%	32%	12%	22%	100%
95% conf. bounds:	(69,000-128,000)	(87,000-148,000)	(174,000-233,000)	(64,000-90,000)	(97,000-187,000)	(584,000-692,000)

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[1] Does not include farms.

[2] Percents are calculated prior to rounding.

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Table 9-8. Estimates, by survey region, of the mean and median age (in years) of underground motor fuel storage tanks(1) (95% confidence bounds about the mean in parentheses)

Survey region	Mean tank age (in years)	Median tank age (in years)
1 Northeast	12 (11-13)	12
2 Southeast	12 (11-14)	11
3 Midwest	12 (11-14)	11
4 Central	12 (9-15)	10
5 Mountain	11 (9-14)	11
6 Pacific	12 (7-18)	11
Total	12 (11-13)	11

(1) Does not include tanks at farms.

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Table 9-9. Estimates, by establishment type, of the mean and median age (in years) of underground motor fuel storage tanks[1] (95% confidence bounds about the mean in parentheses)

Type of establishment	Mean tank age (in years)	Median tank age (in years)
Government & military	12 (10-14)	9
Gas stations owned by major petroleum companies	12 (9-14)	11
Gas stations owned by other companies	14 (13-16)	13
Other fuel-related establishments	12 (10-13)	11
Large non-fuel-related establishments	10 (9-12)	7
Total	12 (11-13)	11

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(1)Does not include tanks at farms.

Table 9-10. Estimates, by survey region, of the mean and median capacity (in gallons) of underground motor fuel storage tanks(1) (95% confidence bounds about the mean in parentheses)

Survey region	Mean tank capacity (in gallons)	Median tank capacity (in gallons)
1 Northeast	4,583 (3,662-5,503)	4,000
2 Southeast	5,744 (4,931-6,557)	6,000
3 Midwest	5,710 (5,064-6,357)	5,000
4 Central	5,176 (4,751-5,601)	4,000
5 Mountain	5,866 (5,711-6,020)	5,000
6 Pacific	6,180 (4,954-7,406)	6,000
Total	5,405 (5,026-5,783)	4,000

(1) Does not include tanks at farms.

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Table 9-11. Estimates, by establishment type, of the mean and median capacity (in gallons) of underground motor fuel storage tanks(1) (95% confidence bounds about the mean in parentheses)

Type of establishment	Mean tank capacity (in gallons)	Median tank capacity (in gallons)
Government & military	**4,342** (3,059-5,626)	**2,000**
Gas stations owned by major petroleum companies	**6,821** (6,120-7,522)	**6,000**
Gas stations owned by other companies	**5,093** (4,513-5,674)	**4,000**
Other fuel-related establishments	**5,687** (4,963-6,410)	**4,000**
Large non fuel-related establishments	**5,261** (4,374-6,149)	**4,000**
Total	**5,405** (5,026-5,783)	**4,000**

(1)Does not include tanks at farms.

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Table 9-12. Estimates, by survey region, of percent of underground motor fuel storage tanks[1,2] that stored specified fuel types within the prior year (95% confidence bounds in parentheses)

Survey region	Percent of tanks that store leaded gasoline	Percent of tanks that store unleaded gasoline	Percent of tanks that store diesel fuel	Percent of tanks that store aviation fuel	Percent of tanks that store gasohol	Percent of tanks that store other types of motor fuel
1 Northeast	28% (19-36%)	48% (36-59%)	23% (13-32%)	2% (1-3%)	0%(3)	< 1% (< 1%)
2 Southeast	33% (30-36%)	39% (34-44%)	23% (18-29%)	2% (1-3%)	2% (1-2%)	2% (1-4%)
3 Midwest	36% (40-42%)	36% (27-46%)	20% (6-34%)	3% (< 6%)	3% (< 6%)	2% (1-4%)
4 Central	33% (31-36%)	39% (28-49%)	23% (16-30%)	3% (1-5%)	1% (< 3%)	1% (< 3%)
5 Mountain	34% (23-45%)	36% (27-44%)	25% (19-31%)	5% (3-8%)	0%(3)	0%(3)
6 Pacific	37% (33-41%)	46% (32-59%)	16% (4-28%)	1% (< 4%)	0%(3)	0%(3)
Total	33% (30-36%)	42% (37-46%)	21% (17-26%)	2% (1-3%)	1% (0-2%)	1% (1-2%)

(1) Does not include tanks on farms.

(2) Row percent may sum to more than 100 percent because some tanks were used to store more than one fuel type during the 12 months prior to the survey.

(3) No tanks were found in this region's sample storing this type of fuel. Hence, no confidence bounds were estimated.

Table 9-13. Estimates, by establishment type, of percent of underground motor fuel storage tanks[1,2] that stored specified fuel types within the prior year (95% confidence bounds in parentheses)

Establishment type	Percent of tanks that store leaded gasoline	Percent of tanks that store unleaded gasoline	Percent of tanks that store diesel fuel	Percent of tanks that store aviation fuel	Percent of tanks that store gasohol	Percent of tanks that store other types of motor fuel
Government and Military	34% (27-41%)	27% (22-31%)	29% (25-32%)	6% (1-11%)	1% (< 2%)	4% (< 8%)
Gas station owned by major petroleum companies	33% (30-36%)	60% (57-62%)	6% (4-9%)	0%(3)	3% (< 6%)	0%(3)
Gas station owned by other companies	36% (33-38%)	50% (46-55%)	13% (9-17%)	0%(3)	1% (< 3%)	1% (< 2%)
Other fuel-related establishments	24% (20-29%)	33% (25-40%)	28% (22-35%)	11% (8-14%)	< 1% (< 1%)	3% (0-6%)
Large non-fuel-related establishments	33% (25-41%)	29% (20-38%)	38% (30-45%)	1% (< 2%)	0%(3)	0%(3)
Total	33% (30-36%)	42% (37-46%)	21% (17-26%)	2% (2-3%)	1% (0-2%)	1% (1-2%)

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(1) Does not include tanks on farms.

(2) Row percents may sum to more than 100 percent because some tanks were used to store more than one fuel type during the 12 months prior to the survey.

(3) No tanks were found in this establishment type storing this type of fuel. Hence, no confidence bounds were estimated.

Table 9-14. Estimates by survey region of the percent of underground motor fuel storage tank systems[1] with selected installation characteristics (95% confidence bounds in parentheses)

Survey region	Percent of tank systems that are fiberglass	Percent of tank systems that are bare steel (i.e. not coated)	Percent of tank systems that have cathodic protection	Percent of tank systems that are installed partially (or completely) below water table	Percent of tank systems that are covered by a paved surface
1 Northeast	10% (4-16%)	5% (2-9%)	4% (2-7%)	21% (13-29%)	73% (55-91%)
2 Southeast	10% (5-15%)	10% (4-17%)	3% (1-5%)	17% (11-23%)	71% (63-80%)
3 Midwest	12% (< 25%)	12% (8-16%)	5% (3-8%)	25% (21-29%)	65% (44-85%)
4 Central	16% (2-29%)	8% (4-12%)	< 1% (< 1%)	12% (2-21%)	74% (62-86%)
5 Mountain	12% (8-15%)	8% (< 17%)	17% (3-30%)	27% (14-40%)	72% (66-79%)
6 Pacific	10% (1-20%)	38% (8-68%)	3% (< 7%)	26% (6-45%)	90% (83-97%)
Total	11% (7-15%)	12% (7-17%)	5% (3-6%)	21% (17-25%)	73% (66-80%)

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[1] Does not include farm tanks.

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Table 9-14. (Cont'd) Estimates by survey region of the percent of underground motor fuel storage tank systems[1] with selected installation characteristics (95% confidence bounds in parentheses)

Survey region	Percent of tank systems that are in a manifolded system	Percent of tank systems that are connected to a pressure pumping delivery systems	Percent of tank systems that have metered dispensing systems	Percent of tank systems that were self-installed	Percent of tank systems that were 2nd-hand when installed
1 Northeast	29% (18-41%)	26% (10-43%)	96% (93-100%)	13% (0-27%)	5% (2-7%)
2 Southeast	22% (15-28%)	29% (25-32%)	88% (83-93%)	25% (17-33%)	6% (1-11%)
3 Midwest	21% (14-27%)	31% (22-40%)	90% (86-94%)	18% (8-28%)	2% (1-4%)
4 Central	18% (9-26%)	25% (13-37%)	89% (81-97%)	44% (22-67%)	7% (< 14%)
5 Mountain	12% (< 23%)	42% (39-45%)	87% (83-91%)	6% (< 18%)	3% (< 6%)
6 Pacific	22% (8-35%)	24% (14-34%)	88% (76-100%)	22% (3-42%)	1% (< 2%)
Total	23% (18-27%)	28% (22-34%)	91% (88-93%)	20% (14-26%)	4% (2-6%)

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[1] Does not include farm tanks.

Table 9-15. Estimates by establishment type of the percent of underground motor fuel storage tank systems[1] with selected installation characteristics (95% confidence bounds in parentheses)

Type of establishment	Percent of tank systems that are fiberglass	Percent of tank systems that are bare steel (i.e. not coated)	Percent of tank systems that have cathodic protection	Percent of tank systems that are installed partially (or completely) below water table	Percent of tank systems that are covered by a paved surface
Goverment and military	6% (2-10%)	15% (8-22%)	7% (3-11%)	27% (19-34%)	46% (33-58%)
Gas stations owned by major petroleum companies	24% (14-34%)	7% (3-12%)	5% (2-9%)	24% (14-34%)	95% (92-99%)
Gas stations owned by other companies	9% (3-14%)	10% (6-15%)	5% (1-8%)	21% (12-29%)	84% (74-94%)
Other fuel-related establishments	8% (4-11%)	9% (2-15%)	3% (< 7%)	33% (20-46%)	68% (60-77%)
Large non-fuel-related establishments	10% (2-18%)	17% (< 38%)	2% (< 5%)	10% (< 20%)	61% (51-71%)
Total	11% (7-15%)	12% (7-17%)	5% (3-6%)	21% (7-25%)	73% (66-80%)

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[1] Does not include farm tanks.

Table 9-15. (cont'd) Estimates by establishment type of the percent of underground motor fuel storage tank systems[1] with selected installation characteristics (95% confidence bounds in parentheses)

Type of establishment	Percent of tank systems that are in a manifolded system	Percent of tank systems that are connected to a pressure pumping delivery systems	Percent of tank systems that have metered dispensing systems	Percent of tank systems that were self-installed	Percent of tank systems that were 2nd-hand when installed
Goverment and military	14% (7-22%)	9% (3-16%)	87% (83-90%)	44% (29-60%)	6% (3-9%)
Gas stations owned by major petroleum companies	24% (16-31%)	58% (47-70%)	100% (99-100%)	10% (1-19%)	1% (< 2%)
Gas stations owned by other companies	24% (17-31%)	32% (26-39%)	98% (96-100%)	9% (4-14%)	1% (< 2%)
Other fuel-related establishments	30% (21-39%)	22% (16-31%)	84% (80-88%)	17% (6-28%)	2% (1-4%)
Large non-fuel-related establishments	21% (8-35%)	14% (3-24%)	80% (71-89%)	20% (8-31%)	10% (4-15%)
Total	23% (18-27%)	28% (22-34%)	91% (88-93%)	20% (14-26%)	4% (2-6%)

[1] Does not include farm tanks.

of the survey regions, ranging from 12 percent in the Pacific region to 20 percent in the Mountain and Central regions. The distributions of tanks at gas stations in the two ownership groups show differences particularly in the Pacific survey region. While 18 percent of the tanks in all survey regions are found at gas stations owned by major petroleum companies, in the Pacific survey region, 29 percent of the tanks are at this type of establishment. The Mountain survey region has the lowest proportion of tanks in this group (11%). And while 32 percent of the tanks in all survey regions are found at gas stations owned by other companies, in the Pacific survey region only 16 percent of the tanks are at gas stations owned by other companies. Tanks at large non-fuel-related establishments account for 33 percent of the tanks in the Pacific survey region, and 14 percent of the tanks in the Central survey region, while they account for 22 percent of the tanks across all survey regions.

B. Selected Tank Characteristics, Analyzed by Region and by Establishment Type

Selected tank characteristics, including tank age, tank capacity, type of motor fuel held in the tank, and installation characteristics, were analyzed by survey region and by establishment type. These analyses are based on a file of 2411 tanks, weighted to represent the national estimate of 638,000 tanks. The results of the analyses of these characteristics are displayed in Table 9-8 through Table 9-15.

1. Tank Age

Tank age was calculated by subtracting the year of installation from the year of interview (1985). If a tank was used (i.e., second-hand) when it was installed, the age of the tank at installation was added to the number of years since installation, to obtain tank age. All information required to compute tank age was present for 69 percent of the tanks surveyed. Tables 9-8 and 9-9 are based on these tanks. They show the mean (or average) age of tanks and the median (or 50th percentile) age of tanks in years, by survey region and establishment type. For tanks in all survey regions, the average age is 12 years, and the median age is 11 years. The average age within survey regions was also 12 years for all regions except Mountain, where the average age was 11 years. The median tank age also was similar for all survey regions.

More differences appear when the average age of tanks is compared across types of establishments. Table 9-9 shows that tanks at gasoline stations owned by other companies (i.e., those not owned by major petroleum companies) tend to be older than tanks at other types of establishments. The mean age of tanks at gas stations owned by other companies is 14 years (compared to a mean of 12 years, overall) and the median age of these tanks is 13 years (compared to a median of 11 years overall). Large non-fuel-related establishments appear to have newer tanks than other establishments, with an average tank age of 10 years, and a median tank age of 7 years.

2. Tank Capacities

Average and median tank capacities also varied within survey regions and establishment types, as may be seen in Tables 9-10 and 9-11. (Nearly all tanks, over 99%, had known capacity.) Across all survey regions and establishment types, the average tank size is 5,405 gallons, and the median tank size is 4,000 gallons. Tanks in the Pacific survey region tend to be larger, with an average tank size of 6180 gallons and a median tank size of 6000 gallons. Tanks in the Northeast survey region tend on average to be smaller, with a mean tank capacity of 4,583 gallons, and a median capacity of 4000 gallons.

Tanks at gas stations owned by major petroleum companies tend to be larger, with an average capacity of 6,821 gallons (compared to the national average of 5,405 gallons), and a median capacity of 6,000 gallons (compared to the national median of 4,000 gallons.) The establishments with the smallest tank capacity are the government and military establishments, where the average tank size is 4,342 gallons and the median tank size is 2,000 gallons.

3. Type of Motor Fuel Stored

Tables 9-12 and 9-13 show the estimates, by survey region and by type of establishment, of the percent of underground tanks that were used to store specific motor fuel types during the prior year. All tanks had data on fuel type. There is not much variation in the percent of tanks that store leaded gasoline across survey regions. For all survey regions together, 33 percent of the tanks store leaded gasoline, and the proportions within survey regions range from a low of 28 percent in the

Northeast region to a high of 37 percent in the Pacific region. Unleaded gasoline is stored in 42 percent of the tanks overall. The regions with the lowest percentage of tanks that store unleaded gasoline are the Midwest and Mountain, each with 36 percent. The region with the highest percentage of tanks that store unleaded gasoline is the Northeast with 48 percent. Diesel fuel is stored in 21 percent of the tanks nationally, but in a slightly lower percentage of tanks in the Pacific survey region (16%).

Tanks that store aviation fuel account for about two percent of the tanks in the continental United States, while tanks that store gasohol and tanks that store other fuel types and fuel blends each account for about one percent of the tanks in the country. Regional variations among these products do not appear to be meaningful.

Some variation in the types of fuels stored within establishment types is expected, since different types of establishments use fuels for different types of vehicles. A smaller percentage of government and military tanks are used to store unleaded gasoline (27%) than the national percentage of 42 percent. Among gas stations, the percent of tanks that store unleaded gasoline is substantially higher that the national percentage, but interestingly enough, the percentage is higher for gas stations owned by major petroleum companies (at 60%) than it is for gas stations owned by other companies (at 51%). Although it is risky to draw any conclusions from such small subsamples, it is not surprising that government and military establishments and other fuel-related establishments account for the majority of tanks that store aviation fuel. (These two categories of establishments include the government and public sector airfields, airports and air services.)

4. Material of Construction

Overall, 11 percent of the underground motor fuel storage tanks in the continental United States are fiberglass. This information was known for 92 percent of tanks, and the estimate of 11 percent fiberglass is based on those with known material of construction. The percent distribution is nearly equal for all survey regions (ranging between 10% and 12% in each region) except for the Central survey region, where the percentage of fiberglass tanks is just slightly higher (16%). There are more striking differences in the percentages of tanks that are fiberglass within establishment types. The percentages of fiberglass tanks at gas stations that are owned by other companies, other fuel-related establishments, and large non-fuel-related establishments are all close to the national percentage of 11 percent. (These establishment types have 9%, 8%, and 10% respectively.) Only 6 percent of the tanks at government and military establishments are fiberglass, while 24 percent of the tanks at gas stations owned by major petroleum companies are fiberglass.

Steel tanks comprise 89 percent of the underground motor fuel storage tanks nationally. According to establishment operators, the majority (about 85%) of steel tanks are coated, based on tanks for which this question was answered. (However, establishment operators did not know if the tanks were bare or coated for 39% of the tanks, and the material of construction was unknown for 8% of the tanks.) Among tanks reported to be coated, the coating material was not reported for 7 percent of the tanks. Among tanks for which the coating material was reported, 58 percent were coated with asphaltic material, 34 percent with coal tar epoxy, and the remainder with urethane (2%), "black coating" (2%), fiberglass/epoxy (1%) or other coatings with less than 1 percent each (and totaling 2% of responses) such as double-wrapped tar tape, red oxide, paint, jenite (creosote and asphalt), tar paint, rust primer and anti-rust paint, etc.

Based on available data, it is estimated that 12 percent of the tanks nationally are bare (uncoated) steel tanks. These bare tanks are found in differing proportions throughout the country. Only five percent of the tanks are reported to be bare steel in the Northeast survey region. However, 38 percent of the tanks in the Pacific survey region are reported to be bare steel. The remaining four survey regions are much closer to or equal to the national proportion.

The variations in the distributions of tanks that are bare steel across establishment types are less pronounced. The lowest percentage is found among gas stations owned by major petroleum companies, where 7 percent of the tanks are reported to be bare steel. Large non-fuel-related establishments have the highest percentage of bare steel tanks, with 17 percent. However, the percentages for all establishment types are within five percentage points of the overall percentage.

5. Cathodic Protection

Only five percent of all tanks were reported to have cathodic protection systems of any type installed to protect them against corrosion, based on the 87 pecent of tanks for which this question was answered. Within survey regions, 17 percent of the tanks in the Mountain survey region were reported to have cathodic protection. There are no other particularly noteworthy divergences from the national proportions across other survey regions or across establishment types.

6. Water Table Level

Establishment operators were asked to indicate how each of the tanks at an establishment were situated in relation to the water table ("completely above", "partially above and partially below", or "completely below"). Establishment operators were able to provide information on the water table level for about 70 percent of the tanks surveyed. Based on the tanks for which responses were given, 21 percent of the tanks are reported to be installed partially or completely below the water table. This percentage varies somewhat across regions, with only 12 percent of the tanks in the Central survey region installed in or beneath the water table. In the Mountain survey region, the highest percentage of tanks (27%) are reported to be installed in or beneath the water table.

Among establishment types, large non-fuel-related establishments have the lowest percentage of tanks reported to be installed in or beneath the water table, with 10 percent. The other fuel-related establishments reported 33 percent of tanks installed partially or completely below the water table. Government and military establishments also have a slightly higher percentage, with 27 percent of tanks at these establishments reported to be installed in or beneath the water table.

7. Surface over the Tank

About 73 percent of the tanks nationally are covered by a paved surface. (Paved surfaces are defined here to include asphalt surfaces, concrete surfaces and surfaces that are made of these materials in combination. They exclude surfaces that are "paved" with gravel or crushed rock. Surface over the tank was known for nearly all tanks -- over 99 percent.) Among the survey regions, the Pacific region has the highest percentage of tanks that are covered by a paved surface, with 90 percent of tanks reported to have this trait. The Midwest survey region has 65 percent of its tanks covered by a paved surface, and this is the lowest proportion among regions. The remaining four regions are all within 2 percentage points of the national percent.

Among establishment types, gas stations have the highest percentage of tanks covered by paved surfaces, with 95 percent of the tanks at gas stations owned by major petroleum companies covered by paved surfaces, and 84 percent of the tanks at gas stations owned by other companies covered by paved surfaces. Government and military establishments have the lowest proportion of tanks under pavement, with 46 percent. Tanks that are under unpaved surfaces may or may not have the same amount or type of traffic over the tank as tanks under paved surfaces. However, tanks under paved surfaces will be more costly to excavate and rebury, should there be a need to remove, replace or repair them.

8. Manifolded Systems

Twenty three percent of all tanks are in manifolded tank systems. (This was known for 99.9% of tanks surveyed.) Manifolded systems were defined, for the purposes of this survey, as two or more underground motor fuel storage tanks that are joined together by pipes or lines prior to the dispenser meters. The average number of tanks per manifolded system is 2.36. The survey region with the highest percentage of tanks in manifolded systems is the Northeast, with 29 percent of tanks in such systems. The Mountain survey region has the lowest percentage of tanks in manifolded systems, with 12 percent. The remaining four regions are all slightly lower than, but very close to the national percentage, ranging from 18 percent to 22 percent.

Other fuel-related establishments have a somewhat higher percentage of tanks in manifolded systems (30%). The establishment type with the lowest percentage of tanks in manifolded systems was the government and military establishments with 14 percent.

9. Types of Pumping Systems

The majority of tanks are reported to be connected to suction pumping systems, based on the 95 percent of tanks for which type of pumping system was known. Overall, 28 percent of the tanks were reported to be connected to pressurized delivery systems. All survey regions were close to the national percentage on this trait, except the Mountain survey region, where 42 percent of the tanks were reported to be connected to pressurized delivery systems. Also, more than half (58%) of the pumping systems at gas stations owned by major petroleum companies are pressurized, which is nearly twice the national percentage. Government and military establishments and large non-fuel-related establishments have much lower percentages of tanks connected to pressure pumping systems, with 9 percent and 13 percent respectively.

10. Metered Dispensing Systems

It is virtually impossible to conduct inventory reconciliation monitoring on tanks that are connected with dispensing systems that do not have meters to record the total amount of fuel dispensed from the tank. Fortunately, 91 percent of the tanks nation-wide have metered dispensing systems, based on 99.8 percent of tanks for which this question was answered. The percentages within each survey region are all within five percentage points of the national percent of tanks with dispenser meters. Some variation in the percentage of tanks with dispenser meters can be seen across establishment types. Nearly all tanks at gas stations (100 percent at gas stations owned by major petroleum companies and 98 percent at gas stations owned by other companies) have metered dispensing systems. The remaining three establishment types are all slightly lower than the national percentage of tanks with metered dispensing systems. Large non-fuel-related establishments have the lowest percentage, with 80 percent of the tanks at this type of establishment connected to metered dispensing systems.

11. Self-Installed Tanks

The identity of the tank installer was known for over half (54%) of tanks surveyed. Based on these tanks with known installers, establishment owners reported that 20 percent of underground motor fuel storage tanks were self-installed (i.e., installed by the establishment or its owners.) However, this percentage varies both across survey region and across establishment type. Percentages of tanks that were self-installed across survey region range from a high of 44 percent in the Central survey region to a low of 6 percent in the Mountain

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survey region. Among establishment types, 44 percent of the government and military tanks were self-installed, which was the highest percentage among the establishment types. The establishment types with the lowest percent of self-installed tanks are the gas stations owned by other companies (with 9% self-installed) and gas stations owned by major petroleum companies (with 10% self-installed).

12. Secondhand Tanks

A small percentage of the tanks surveyed were secondhand when they were installed at their current location, based on the 81 percent of tanks for which this information was ascertained. It is estimated that four percent of the tanks nationally were installed secondhand. (As explained above, if a tank was secondhand when installed, its total age was calculated to include its age at the time it was installed.) Because of the small percentage of tanks with this trait, it is risky to draw many conclusions about the percent distribution of this trait within survey regions and establishment types. It may be noted with some caution that a higher percentage of tanks at large non-fuel-related establishments (10%) were secondhand tanks, while a lower percent of tanks at gas stations in both ownership categories and tanks in the Pacific survey region (about 1% for each category) were secondhand.

IV. LEAK STATUS OF UNDERGROUND MOTOR FUEL STORAGE TANKS

A total of 439 individual and manifolded tank systems at business and government establishments were tested as a part of the physical tank testing phase of the survey. The analyses in this subsection are based on two related data files. The first is the file of 412 individual and manifolded tank systems for which there are conclusive test results. The second data file consists of the 383 conclusive test results which refer to single-tank systems. The sample of individual and manifolded tank systems, is analyzed in tables where the characteristics being examined apply to entire systems, whether they consist of individual tanks and their lines, or manifolded tanks and their lines. The sample of individual tank systems, is analyzed in tables where the characteristics being examined apply to individual tanks in systems rather than manifolded tanks in systems (such as, for example, tank capacity.)

A. Leak Status of Tank Systems within Survey Regions and Establishment Types

Detailed analyses are given below for the leak status distribution of tank systems. On an establishment basis, an estimated 117,000, or 36 percent, of establishments have one or more tank systems judged to be leaking under test conditions. This is comparable to the percentage on a tank system basis.

Within the continental United States 35 percent of the underground motor fuel storage tank systems at business and government establishments are judged to be leaking under test conditions, based on all tests with conclusive results. The distributions of percentages of leaking tank systems across survey regions and establishment types are displayed in Tables 9-16 through 9-18. The estimated number of tank systems judged to be leaking is 189,000. This excludes tank systems for which test results were inconclusive. (Therefore, this estimated number, when divided by the estimated total number of tanks, will not give the percentage shown.)

Table 9-16. Estimated number and percent of tank systems [1,2] judged to be leaking under test conditions within each survey region (95% confidence bounds in parentheses)

Survey Region	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
1 Northeast	98	57 (37-77)	39% (32-45%)
2 Southeast	104	42 (19-65)	36% (22-50%)
3 Midwest	82	34 (22-46)	28% (19-37%)
4 Central	48	26 (14-38)	46% (22-70%)
5 Mountain	39	11 (3-18)	33% (17-48%)
6 Pacific	41	20 (11-30)	28% (18-38%)
Total	412	189 (153-226)	35% (30-40%)

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[1] In this table tank system test results are reported for single tank systems unless multiple tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in this table.

[2] Does not include farm tanks.

[3] Includes all tank systems with conclusive test results. Excludes tank systems for which test results were inconclusive.

Table 9-17. Estimated number and percent of tank systems[1],[2] judged to be leaking under test conditions within establishment types (95% confidence bounds in parentheses)

Type of Establishment	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
Government and military	55	29 (5-54)	36% (16-55%)
Gas stations owned by major petroleum companies	62	25 (11-38)	32% (19-45%)
Gas stations owned by other companies	155	56 (40-71)	30% (22-37%)
Other fuel-related establishments	64	35 (25-45)	57% (43-71%)
Large non-fuel-related establishments	76	45 (17-71)	33% (18-47%)
Total	412	189 (153-226)	35% (30-40%)

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[1] In this table tank system test results are reported for single tank systems unless multiple tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in this table.

[2] Does not include farm tanks.

[3] Includes all tanks with conclusive test results. Excludes tanks for which test results were inconclusive.

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Table 9-18. Estimates by survey region and establishment type of percent of underground motor fuel storage tank systems [1,2,3] judged to be leaking under test conditions (95% confidence bounds in parentheses)

	Establishment type					
Survey region	Government and military	Gas stations owned by major petroleum companies	Gas stations owned by other companies	Other fuel-related establishments	Large non-fuel related establishments	All establishment types
1 Northeast	60% (40-80%)	50% (50-50%)	31% (19-43%)	44% (4-85%)	32% (12-52%)	39% (32-45%)
2 Southeast	17% (0-34%)	55% (43-66%)	29% (20-37%)	60% (37-83%)	36% (0-73%)	36% (22-50%)
3 Midwest	0%[4]	12% (0-39%)	31% (12-51%)	68% (49-88%)	0%[4]	28% (19-37%)
4 Central	29% (0-76%)	40% (27-53%)	41% (12-70%)	60% (40-80%)	75% (38-100%)	46% (22-70%)
5 Mountain	60% (36-84%)	0%[4]	18% (0-52%)	38% (33-42%)	50% (12-88%)	33% (17-48%)
6 Pacific	20% (0-61%)	29% (18-39%)	0%[4]	50% (0-100%)	30% (0-75%)	28% (18-38%)
All regions	36% (16-55%)	32% (19-45%)	30% (22-37%)	57% (43-71%)	33% (18-47%)	35% (30-40%)

[1] In this table tank system test results are reported for single tank systems unless multiple tanks were tested as part of a manifolded tank system that could not be broken apart. These manifolded tank systems tested together are included in this table.

[2] Does not include farm tanks.

[3] Includes all tanks with conclusive test results. Excludes tanks for which test results were inconclusive (sample size = 412 cases).

[4] No eligible sampled establishments of this type were found in this survey region, so the percent and confidence bounds on it were not estimated.

As is shown in Table 9-16, the Central survey region has the highest percentage of leaking tank systems, with 46 percent. The regions with the lowest percentage of leaking tank systems are the Midwest and the Pacific, each with 28 percent. The Northeast survey region has the highest estimated number of leaking tank systems (57,000) while the Mountain survey region has the lowest estimated number (11,000).

Table 9-17 shows the number and percent of tank systems judged to be leaking by establishment type. Fuel-related establishments other than gas stations have the highest percentage of leaking tank systems, with 57 percent judged to be leaking. Gas stations owned by other companies have the lowest percentage of tank systems judged to be leaking, with 30 percent, but account for the largest estimated number (56,000) of tank systems judged to be leaking.

The percent of tank systems judged to be leaking under test conditions within each category of establishment type and survey region is displayed in Table 9-18. Small sample sizes within many of the cells of this table result in wide confidence bounds and some difficulty in interpretation. The five cells with the highest percentages of tank systems judged to be leaking were government and military tank systems in the Northeast and Mountain survey regions, tank systems at other fuel-related establishments in the Midwest and Central survey regions, and large non-fuel-related establishments in the Central survey region. The five cells with the lowest percentages of tank systems judged to be leaking were government and military tank systems, tank systems at gas stations owned by major petroleum companies, and tank systems at large non-fuel-related establishments in the Midwest survey region, tank systems at gas

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stations owned by major petroleum companies in the Mountain survey region, and tank systems at gas stations owned by other companies in the Pacific survey region.

B. Characteristics Associated with Leaking Tanks

Selected tank characteristics, including tank age, tank capacity, type of motor fuel held in the tank, and installation characteristics were analyzed by tank system leak status. The results of these analyses, including the sample size, estimated number of tank systems leaking, and percent of tank systems leaking, are displayed in Tables 9-19 through 9-23.

1. Tank Age and Material

Table 9-19 shows the estimated number and percent of tank systems that are judged to be leaking under test conditions within five categories of tank age. While overall, 35 percent of tank systems are judged to be leaking, 57 percent of the tank systems that are more than twenty years old are judged to be leaking under test conditions. However, tank systems that are thirteen through twenty years old form the age category with the smallest percentage leaking. Note, however, that this difference does not appear to be statistically significant. Each of these arbitrary age categories accounts for a similar number of leaking tank systems, ranging from an estimated 22,000 tank systems to 27,000 tank systems.

Table 9-19A provides a more detailed look at percent judged to be leaking broken down by both age and tank material. There

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Table 9-19. Estimated number and percent of tank systems[1,2] judged to be leaking under test conditions within tank age categories[3] (95% confidence bounds in parentheses)

Tank age categories	Sample size[4]	Number of tanks judged to be leaking (in 1,000's)	Percent of tanks judged to be leaking
< 5 years old	54	27 (4-51)	38% (19-57%)
5-8 years old	52	25 (13-38)	35% (23-47%)
9-12 years old	57	26 (9-42)	36% (20-52%)
13-20 years old	56	22 (8-35)	30% (15-45%)
> 20 years old	36	26 (14-37)	57% (39-75%)
Age unknown	128	50 (21-79)	29% (19-39%)
Total	383	177 (139-214)	35% (30-40%)

[1] In this table, tank system test results are reported for single tank systems. Tanks tested as a part of a manifolded tank system that was not broken apart are not included in the table.

[2] Does not include farm tanks.

[3] Tank age, as calculated from year of installation and age at installation (if second-hand), was missing for 128, or 33% of the tanks.

[4] Includes all individually tested tank systems with conclusive results. Excludes tank systems for which test results were inconclusive, and tank systems tested as part of a manifolded tank system.

Table 9-19A. Estimated number and percent of tank systems[1,2] judged to be leaking under test conditions, by age and material of tank construction[3] (95% confidence bounds in parentheses)

Tank material and age categories	Sample size	Number of tanks judged to be leaking (in 1,000's)	Percent of tanks judged to be leaking
Steel:			
< 5 years old	46	23 (< 47)	38% (11-65%)
5-8 years old	44	21 (12-30)	38% (24-45%)
9-12 years old	46	18 (5-31)	31% (13-49%)
13-20 years old	51	22 (8-35)	33% (17-50%)
> 20 years old	35	26 (14-39)	58% (39-77%)
Fiberglass:			
< 5 years old	7	2 (< 5)	26% (< 77%)
5-20 years old	20	10 (< 20)	36% (17-55%)

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[1] In this table, tank system test results are reported for single tank systems. Tanks tested as a part of a manifolded tank system that was not broken apart are not included in the table.

[2] Does not include farm tanks.

[3] Respondents were unable to provide age or material of construction for 33 percent and 8 percent, respectively, of tested tanks.

Table 9-20. Estimated number and percent of tank systems [1,2] judged to be leaking under test conditions within tank capacity category (95% confidence bounds in parentheses)

Tank Capacity	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
≤ 1100 gallons	82	29 (13-45)	23% (13-34%)
1101 to 3999 gallons	58	21 (9-32)	27% (18-37%)
4000 to 4999 gallons	61	30 (11-49)	39% (24-55%)
5000 to 5999 gallons	17	13 (3-24)	61% (35-86%)
6000 to 7999 gallons	50	25 (4-45)	37% (14-60%)
8000 to 9999 gallons	33	15 (2-28)	34% (11-58%)
10,000 to 11,999 gallons	60	34 (17-51)	45% (29-62%)
≥ 12,000 gallons	22	11 (3-19)	43% (30-57%)
Total	383	177 (139-214)	35% (30-40%)

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[1] In this table tank system test results are reported for single tank systems. Tank tested as a part of a manifolded tank system that was not broken apart are not included in the table.

[2] Does not include farm tanks.

[3] Includes all individually tested tank systems with conclusive results. Excludes tank systems for which test results were inconclusive, and tank systems tested as part of a manifolded tank system.

Table 9-21. Estimates by fuel types stored during the prior year of the number and percent of tank systems[1,2] judged to be leaking under test conditions (95% confidence bounds in parentheses).

Fuel types stored during prior year	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
Leaded gasoline	130	32 (15-49)	18% (9-26%)
Unleaded gasoline	171	72 (53-91)	33% (25-41%)
Diesel fuel	97	73 (48-99)	57% (47-67%)

[1] In this table tank system test results are reported for single tank systems unless multiple tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are not included in the table.

[2] Does not include farm tanks.

[3] Includes all tank systems with conclusive test results. Excludes tank systems for which test results were inconclusive.

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Table 9-22. Estimated number and percent of tank systems[1,2] judged to be leaking under test conditions for single tanks and tank systems in manifolded systems (95% confidence bounds in parentheses).

	Sample size[3]	Number of tank systems judged to be leaking (in 1,000's)	Percent of tank systems judged to be leaking
Single tanks systems (not manifolded)	338	140 (105-174)	31% (26-36%)
Tanks in manifolded systems	74	50 (19-80)	54% (39-68%)
Total	412	189 (153-226)	35% (30-40%)

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[1] In this table tank system test results are reported for single tank systems unless multiple tank systems were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in this table.

[2] Does not include farm tanks.

[3] N1 = Tank systems with conclusive test results. Excludes tank systems for which test results were inconclusive.

Table 9-23. Estimates number and percent of tank systems[1] judged to be leaking under test conditions for tank systems with selected installation characteristics (95% confidence bounds in parentheses).

Installation characteristics	Sample size[2]	Percent of systems judged to be leaking	Number of systems judged to be leaking (in 1,000's)
Fiberglass tanks	30	31% (15-48%)	12 (1-24)
Bare (uncoated steel) tanks	33	32% (14-49%)	14 (0-28)
Coated steel tanks	192	38% (30-46%)	97 (65-128)
Tanks with cathodic protection installed	10	60% (0-100%)	9 (< 25)
Tanks installed partially or completely below the water table	40	47% (25-69%)	23 (9-36)
Tanks covered by a paved surface	263	39% (32-45%)	136 (103-198)
Tanks connected to a pressure pump delivery system	71	41% (27-55%)	37 (21-52)
Tanks with metered dispensing systems	351	36% (31-40%)	164 (130-198)
Tanks that were self-installed	42	23% (31-40%)	14 (3-26)
Tanks that were 2nd-hand when installed	13	52% (26-78%)	9 (4-14)
National totals[3]	383	35% (30-40%)	177 (139-214)

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[1] Does not include farm tanks.

[2] Includes all individually tested tank systems with conclusive results. Excludes tank systems for which test results were inconclusive, tanks tested as part of a manifolded tank system.

[3] Since the categories overlap, the national totals are given to provide a reference point, not as the total of the rows alone.

is some indication that the oldest steel tanks (> 20 years old) may have a higher proportion leaking than younger steel tanks. A comparison of percent judged to be leaking by tank material cannot be made for tanks more than 20 years old, since no fiberglass tanks that old were found in the survey. For age categories where a comparison can be made by tank material, no significant differences appear.

2. Tank Capacity

While the percentage of tank systems judged to be leaking under test conditions nationally is 35 percent for all tested tank systems, there is some variation in the percentage across size categories. Table 9-20 displays the estimated number and percent of tank systems judged to be leaking under test conditions within eight arbitrary size categories. The percentage of tank systems judged leaking is somewhat lower than the national percentage in the two smallest size categories. An estimated 23 percent of the tank systems that are 1100 gallons or less are judged to be leaking, and 27 percent of the tank systems ranging in size from 1101 to 3999 gallons are judged to be leaking. The size categories with the largest percentages of tank systems that are judged to be leaking are systems with tanks that are 5000 to 5999 gallons, with 61 percent; systems with tanks that are 10,000 to 11,999 gallons, with 45 percent; and systems with tanks that are 12,000 or more gallons, with 44 percent. The size categories with the largest estimated numbers of leaking tank systems are those systems with tanks that are 10,000 to 11,999 gallons, and 4,000 to 4,999 gallons.

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3. Type of Motor Fuel Stored

There were interesting differences in the leak status of tank systems depending upon the type of motor fuel they had stored during the prior year, as may be seen in Table 9-21. Among tank systems that store unleaded gasoline the percent leaking under test conditions is 33 percent which is nearly the same as the national percentage. However, among tank systems used to store leaded gasoline, only 18 percent, or about half of the national percentage, are judged to be leaking. Among tank systems storing diesel fuel, the percent judged to be leaking is 57 percent, or nearly two-thirds more than the national percentage. Very small numbers of tank systems used to store other fuel types such as aviation fuel and gasohol were tested, so reliable estimates of leak status can not be provided for tanks storing these fuel types.

4. Manifolded Systems

A somewhat higher proportion of the tank systems that are part of a manifolded tank system are judged to be leaking under test conditions, as is displayed in Table 9-22. Among tank systems that are a manifolded system of two or more tanks, or are individually tested members of such a system, 54 percent of the tank systems are leaking, compared with single tank systems, where 31 percent of the tank systems are leaking.

5. Material of Construction

Single-tank systems with tanks made of fiberglass, coated steel and bare (uncoated) steel were analyzed separately, with the results displayed in Table 9-23. The percent of tank systems judged to be leaking under test conditions within each category of material of construction was nearly the same as the overall percent: compared to 35 percent of tank systems judged to be leaking overall, 31 percent of the systems with fiberglass tanks are leaking, 32 percent of the systems with bare steel tanks are leaking, and 38 percent of the systems with coated steel tanks are leaking. Systems with coated steel tanks account for the majority of all tank systems, and therefore not surprisingly account for the largest number of tank systems judged to be leaking within construction material type.

6. Cathodic Protection

Only a small percentage (about 5% nationally) of tank systems have cathodic protection, and a small number of these systems were tested. The results of these tests for ten systems with cathodic protection are displayed in Table 9-23 and show that 60 percent of cathodically protected tank systems are estimated to be leaking. However, the confidence bounds on this estimate are not tight. In fact, the 95 percent confidence limits range from 0-100 percent. A tighter bound can be constructed by requiring a lower confidence: for example, the 50 percent confidence bounds are 33-87 percent.

This result should not be taken to imply that cathodic protection, when properly installed, maintained, checked by the local establishment operator, and covering the entire tank system is not an effective leak prevention system in principle. However, it does raise a question that would bear further investigation, namely, how feasible it is to achieve the above conditions in practice. A possible explanation for the high proportion judged to be leaking among cathodically protected tank systems is that such protections are only judged worth the installation expense for tank systems believed to be at high risk of leaking. Thus, the figure would be more a description of the tank system universe to which cathodic protection is applied than a measure of what would happen were it to be adopted on a wider basis.

7. Water Table Level

Systems with tanks that are installed in or beneath the water table may be more susceptible to corrosion than tanks that are installed above the water table. Based on an analysis of forty tank systems with tanks reported to be installed in or beneath the water table, it is estimated that 47 percent of the tank systems with tanks installed in or beneath the water table are leaking under test conditions. This is a somewhat higher percentage than the national percentage of 35 percent of systems leaking.

8. Surface over the Tank

Tank systems with tanks that are covered by a paved surface might be expected to be more protected than tank systems with tanks that are not covered by pavement. However, 37 percent of the tank systems with tanks covered by paved surfaces were judged to be leaking under test conditions, which is nearly identical to the overall percentage of tank systems that are leaking (35%).

9. Type of Pumping System

Conclusive test results were obtained for 71 tanks with pressure pumping delivery systems. The results of the analysis of these tests are displayed in Table 9-23. Under test conditions, 41 percent of tank systems that include a pressure pumping delivery system are judged to be leaking. This percentage is only slightly higher than the overall percentage (35%) of tank systems that were judged to be leaking.

10. Metered Dispensing Systems

As shown in Table 9-23, based on tests of 351 tank systems, 36 percent of tanks systems with metered dispensing systems are judged to be leaking under test conditions. This percentage is nearly identical to the overall percentage of tanks judged to be leaking.

11. Self-Installed Tanks

Forty-two of the tank systems for which conclusive test results are available were reported to be installed by the establishment itself. The leak status of these self-installed tank systems is displayed in Table 9-23. Among self-installed tank systems, 23 percent were judged to be leaking, which is twelve percentage points lower than the overall percentage of 35 percent.

12. Secondhand Tanks

About 4 percent of the tanks overall were secondhand when installed. Thirteen systems with secondhand tanks were included in the tank testing program and provided conclusive test results, which are displayed in Table 9-23. Based on this small number of conclusive tests, 52 percent of the systems with secondhand tanks were found to be leaking under test conditions.

V. LEAK RATES OF UNDERGROUND MOTOR FUEL STORAGE TANK SYSTEMS

This section provides an analysis of the estimated mean and median leak rates for tank systems that were judged to be leaking under test conditions. Analyses of mean (average) leak rates are based only on those tank system test results which provided valid system leak rates. Tank systems with leak rates that were coded by the test crew as "unquantifiably large" are excluded from the calculations of the mean leak rates. These comprise 20 percent of the tank systems judged to be leaking. The largest quantified leak rate (after adjustment) was 3.04 gallons per hour. Tank systems that were judged to be leaking and have unquantifiably large leaks were included in the analyses to derive the median leak rates, however. The leak rates reported in this section, whether mean or median, are rates in gallons per hour as adjusted to operating pressures. The adjustment procedure is described in detail in Section 8 and Appendix D of this report.

Each table describes in footnotes the set of test results each column is based on. The medians are based on more cases than the means, since the unquantifiably large leaks are included in calculating the median but not in calculating the mean. Further, some tables include results from manifolded systems not separated for testing, and others, based on characteristics of individual tanks (such as tank age), do not. The total mean and median leak rates are different in these two groups. The overall mean leak rate, based on all quantified tank systems judged to be leaking (118 cases) is 0.32 gallons per hour (0.24-0.39 gallons per hour). The mean for the tests which are of single tanks and associated piping (109 cases) is 0.31 gallons per hour (0.23-0.39 gallons per hour). The median leak rate for all tests (149 cases) is 0.25, while the median for single tank system tests (138 cases) is 0.21.

Mean leak rates for tanks with quantified leak rates are calculated as the weighted arithmetic mean, using sample weights, which allows us to project from the sample to the universe. It is presented as a commonly used and well understood measure of "average" value. However, the mean has two drawbacks which the median does not suffer from: data from unquantifiably large leaks cannot be incorporated in calculating the mean (which biases the mean towards zero); and a single large quantified value can affect the mean greatly (pulling it away from zero), while having no impact on the median. The median is the "middle value" -- i.e., half the values are larger, and half are smaller (including the unquantifiably large leaks at the large end of the scale). It is calculated on an unweighted basis. In a data set with a non-symmetric distribution and significant outliers, the mean and median measure different things, and a discrepancy between them indicates skewness or outliers in the data, which should be kept in mind in undertaking any interpretation.

The overall mean leak rate for tanks leaking under test conditions is 0.32 gallons per hour, and the median leak rate is 0.25 gallons per hour. The distribution of observed leak rates (adjusted to operating conditions) of the 149 tank systems judged to be leaking is shown below. Note that the intervals are not of equal width.

Interval	Proportion of test results in interval
Up to 0.0549	11%
(0.0550-0.149)	30%
(0.150-0.249)	10%
(0.250-0.349)	5%
(0.350-0.449)	5%
(0.450-0.549)	5%
(0.550-1.49)	10%
Quantified, >1.49	3%
Unquantifiably large	21%

A. Mean and Median Leak Rates within Survey Regions and Establishment Types

Within survey regions, mean leak rates for leaking tank systems ranged from a low of 0.24 gallons per hour for the Northeast survey region to a high of 0.48 gallons per hour for the Central survey region (Table 9-24). The Midwest and Pacific survey regions have the lowest median leak rates (of 0.13 gallons per hour) and the Mountain survey region has the highest median leak rate (0.44 gallons per hour) followed closely by the Central survey region with 0.41 gallons per hour.

Within establishment types, leaking tank systems at government and military establishments, gas stations owned by other companies and large establishments have leak rates that range between 0.24 and 0.26 gallons per hour, which is below the overall average of 0.32 gallons per hour (Table 9-25). Leaking tank systems at gas stations owned by major petroleum companies

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Table 9-24. Estimates by survey region mean and median leak rates among tank systems[1,2] judged by be leaking under test conditions (95% confidence bounds in parentheses)

Survey Region	Sample Size (N3)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N4)[5]	Median[4] adjusted leak rate (gph)
1 Northeast	29	0.24 (0.23-0.26)	38	0.22
2 Southeast	28	0.30 (0.17-0.43)	39	0.34
3 Midwest	23	0.32 (0.06-0.57)	26	0.13
4 Central	17	0.48 (0.26-0.71)	22	0.41
5 Mountain	9	0.34 (0.27-0.41)	12	0.44
6 Pacific	12	0.33 (0.02-0.69)	12	0.13
Total	118	0.32 (0.24-0.39)	149	0.25

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[1] In this table tank system tests results are reported for single tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in this table.

[2] Does not include farm tanks.

[3] Leak rates of leaking tank systems were adjusted to operating pressure.

[4] Calculation of median adjusted leak rate included tank systems judged to have unquantifiably large leaks.

[5] N3 = Number of tank systems judged to be leaking under tests conditions that had quantifiable leak rates.

N4 = N3 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

Table 9-25. Estimates by establishment type of mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions (95% confidence bounds in parentheses)

Establishment Type	Sample size (N3)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N4)[5]	Median[4] adjusted[3] leak rate (gph)
Government and military	14	0.26 (0.06-0.47)	20	0.27
Gas stations owned by major petroleum companies	18	0.42 (0.18-0.68)	21	0.29
Gas stations owned by other companies	30	0.24 (0.13-0.34)	46	0.28
Other fuel-related establishments	33	0.45 (0.20-0.71)	36	0.32
Large non-fuel related establishments	23	0.25 (0.14-0.36)	26	0.14
Total	118	0.32 (0.24-0.39)	149	0.25

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[1] In this table tank system tests results are reported for single tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. These tank systems are included in this table.

[2] Does not include farm tanks.

[3] Leak rates of leaking tank systems were adjusted to operating pressure.

[4] Calculation of median adjusted leak rate includes tank systems judged to have unquantifiably large leaks.

[5] N3 = Number of tank systems judged to be leaking under test conditions that had quantifiable leak rates.

N4 = N3 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

and other fuel-related establishments have mean leak rates that are higher (0.42 and 0.45 gallons per hour respectively) than the overall average. Leaking tank systems at large non-fuel-related establishments have a median leak rate that is lower (at 0.14 gallons per hour) than the overall median rate of 0.25 gallons per hour.

B. Mean and Median Leak Rates for Tank Systems with Selected Characteristics

Tables 9-26 through 9-30 below display analyses of the mean and median leak rates for leaking tank systems with selected characteristics. The characteristics include tank age, tank size, type of product held in the tank, and various installation characteristics.

1. Mean and Median Leak Rates within Tank Age Categories

Table 9-26 shows the mean and median leak rates for the tanks judged to be leaking under test conditions. Leaking tanks that are less than five years old and leaking tanks of unknown age have the highest mean leak rate (0.46 gallons per hour). Leaking tanks that are less than five years old also have the highest median leak rate.

The lowest mean and median leak rates were found among leaking tanks that are five to eight years old and leaking tanks that are more than 20 years old.

Table 9-26. Estimated mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions within tank age categories. (95% confidence bounds in parentheses)

Tank Age Categories	Sample size (N5)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N6)[5]	Median[4] adjusted[3] leak rate (gph)
< 5 years old	14	0.46 (0.20-0.71)	21	0.71
5-8 years old	17	0.14 (0.09-0.18)	20	0.11
9-12 years old	20	0.27 (0.12-0.42)	21	0.18
13-20 years old	10	0.22 (0.10-0.34)	18	0.52
> 20 years old	17	0.15 (0.11-0.20)	21	0.16
Age unknown	30	0.46 (0.21-0.71)	36	0.39
Total	109	0.31 (0.23-0.39)	138	0.21

[1] In this table tank system test results are reported for single tank systems. Tank systems that were tested as a part of a manifolded tank system that was not broken apart are not included.

[2] Does not include farm tanks.

[3] Leak rates of leaking tank systems were adjusted to operating pressure.

[4] Calculation of median adjusted leak rate includes tank systems judged to have unquantifiably large leaks.

[5] N5 = Number of tank systems judged to be leaking under tests conditions that had quantifiable leak rates.

N6 = N5 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

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Table 9-27. Estimated mean and median leak rates among tank sytems [1,2] judged to be leaking under test conditions within tank size categories. (95% confidence bounds in parentheses)

Tank Size Categories	Sample Size (N5)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N6)[5]	Median[4] adjusted[3] leak rate (gph)
≤ 1100 gallons	16	0.14 (0.08-0.21)	21	0.10
1101 to 3999 gallons	13	0.26 (0.09-0.43)	16	0.18
4000 to 4999 gallons	18	0.20 (0.13-0.28)	24	0.21
5000 to 5999 gallons	6	0.15 (0.11-0.18)	10	0.23
6000 to 7999 gallons	10	0.35 (-0.07-0.77)	17	1.24
8000 to 9999 gallons	8	0.53 (0.30-0.76)	12	0.89
10,000 to 11,999 gallons	28	0.30 (0.18-0.43)	28	0.12
≥ 12,000 gallons	10	0.83 (-0.05-1.72)	10	0.37
Total	109	0.31 (0.23-0.39)	138	0.21

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[1] In this table tank system test results are reported for single tank systems. Tank systems that were tested as a part of a manifolded tank system that was not broken apart are not included.

[2] Does not include farm tanks.

[3] Leak rates of leaking tank systems were adjusted to operating pressure.

[4] Calculation of median adjusted leak rate includes tank systems judged to have unquantifiably large leaks.

[5] N5 = Number of tank systems judged to be leaking under test conditions that had quantifiable leak rates.

N6 = N5 + those tanks judged to be leaking under test conditions that had unquantifiably/large leak.

Table 9-28. Estimates by fuel types stored during the prior year of the mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions (95% confidence bounds in parentheses)

Fuel types	Sample size[5] (N3)	Mean adjusted[3] leak rate (gph)	Sample size (N4)[5]	Median[4] adjusted[3] leak rate
Leaded gasoline	120	0.22 (0.14-0.31)	24	0.22
Unleaded gasoline	42	0.36 (0.25-0.47)	60	0.49
Diesel fuel	50	0.27 (0.17-0.37)	56	0.14

[1] In this table tank system test results are reported for single tank systems unless the tank systems were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are not included in the table.

[2] Does not include farm tanks.

[3] Leak rates of leaking tank systems were adjusted to operating pressure.

[4] Calculation of median adjusted leak rate includes tank systems judged to have unquantifiably large leaks.

[5] N3 = Number of tank systems judged to be leaking under test conditions that had quantifiable leak rates.

N4 = N3 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

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Table 9-29. Estimated mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions for tanks in manifolded systems and single tanks. (95% confidence bounds in parentheses.)

Tank type	Sample Size (N3)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N4)[5]	Median[4] adjusted leak rate (gph)
Single tanks (not manifolded)	93	0.27 (0.20-0.35)	109	0.16
Tanks in manifolded systems	25	0.49 (0.22-0.75)	40	0.71
Total	118	0.32 (0.24-0.39)	149	0.25

[1] In this table tank system test results are reported for single tank systems unless the tanks were tested as a part of a manifolded tank system that was not broken apart. These manifolded tank systems are included in the table.

[2] Does not include farm tanks.

[3] Leak rates of leaking tanks were adjusted to operating pressure.

[4] Calculation of median adjusted leak rate included tank systems judged to have unquantifiably large leaks.

[5] N3 = Number of tank systems judged to be leaking under test conditions that had quantifiable leak rates.

N4 = N3 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

Table 9-30. Estimated mean and median leak rates among tank systems[1,2] judged to be leaking under test conditions for tanks with selected installation characteristics. (95% confidence bounds in parentheses.)

	Sample Size (N5)[5]	Mean adjusted[3] leak rate (gph)	Sample size (N6)[5]	Median[4] adjusted leak rate (gph)
Fiberglass tanks	110	0.42 (0.22-0.61)	10	0.14
Bare (uncoated steel) tanks	8	0.60 (0.12-1.08)	10	0.39
Coated steel tanks	55	0.26 (0.19-0.32)	75	0.23
Tanks installed partially or completely below the water table	16	0.49 (0.09-0.89	19	0.20
Tanks covered by a paved surface	79	0.29 (0.22-0.37)	100	0.20
Tanks connected to a pressure pump delivery system	23	0.25 (0.12-0.39)	29	0.18
Tanks with metered dispensing systems	101	0.32 (0.23-0.40)	129	0.22
Tanks that were self-installed	9	0.26 (-0.05-0.56)	11	0.13
Total	109	0.31 (0.23-0.39)	138	0.21

[1] In this table tank system test results are reported for single tank systems. Tanks that were tested as a part of a manifolded tank system that was not broken apart are not included.

[2] Does not include farm tanks.

[3] Leak rates of leaking tank systems were adjusted to operating pressure.

[4] Calculation of median adjusted leak rate included tank systems judged to have unquantifiably large leaks.

[5] N5 = Number of tank systems judged to be leaking under tests conditions that had quantifiable leak rates.

N6 = N5 + those tank systems judged to be leaking under test conditions that had unquantifiably large leaks.

2. Mean and Median Leak Rates within Tank Size Categories

Table 9-27 shows the mean and median leak rates for eight size categories among tank systems judged to be leaking under test conditions. Systems with tanks that are 12,000 gallons or more in size have the largest mean leak rate (of 0.83 gallons per hour), and systems with tanks in the smallest size category (1100 gallons or less) have both the smallest mean leak rate (0.14 gallons per hour) and the smallest median leak rate (0.10 gallons per hour). The tank size category with the largest median leak rate is the 6000 to 7999 gallon category, where the median was 1.24 gallons per hour, due in large part to the fact that seven of the seventeen tanks tested in this category have unquantifiably large leaks.

3. Mean and Median Leak Rates by Types of Motor Fuel Stored

Table 9-28 shows mean and median leak rates for leaking tanks storing different types of motor fuels. Leaking tank systems that store unleaded gasoline have the highest mean (0.35 gallons per hour) and median (0.49 gallons per hour) leak rates. Leaking tank systems that store leaded gasoline have the lowest mean leak rate (of 0.22 gallons per hour), but leaking diesel tank systems have the lowest median leak rate (of 0.14 gallons per hour).

4. Mean and Median Leak Rates for Manifolded Tank Systems

Table 9-29 shows the mean and median leak rates for leaking tanks that are in single tank systems and those that are in manifolded tank systems. Both the mean and the median leak rates are higher for leaking tank systems that are manifolded. Leaking Tank systems that are manifolded have a mean leak rate of 0.49 gallons per hour (which is nearly 50% higher than the overall mean leak rate of 0.31 gallons per hour) and a median leak rate of 0.71 gallons per hour, which is nearly three times greater than the overall median leak rate of 0.25 gallons per hour.

5. Material of Construction

Table 9-30 shows the mean and median leak rates for leaking tank systems that have tanks which are fiberglass, bare (uncoated) steel, and coated steel. Leaking tank systems with tanks that are bare steel have the highest mean (0.60 gallons per hour) and median (0.39 gallons per hour) leak rates, but the category also has a small sample size. Leaking tank systems with coated steel tanks have the lowest mean leak rate, of 0.25 gallons per hour. Although there are a large number of tank systems with unquantifiably large leaks in this category, the median leak rate is only 0.23 gallons per hour.

6. Water Table Level

The mean leak rate for leaking tank systems installed in or beneath the water table is 0.49 gallons per hour, based on 16

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tank systems tested (see Table 9-30). The median leak rate among these tanks is 0.20 gallons per hour.

7. Surface over Tank

As is shown in Table 9-30, the mean and median leak rates for tank systems where the tank is covered by a paved surface is nearly equal to the overall mean and median leak rates.

8. Mean and Median Leak Rates for Tank Systems with Pressure Pump Distribution Systems

Leaking tank systems with pressurized distribution systems have lower mean and median leak rates than leaking tank systems overall, as is shown in Table 9-30. The mean leak rate for tank systems with pressurized distribution systems is 0.25 gallons per hour, and the median is 0.18 gallons per hour.

9. Mean and Median Leak Rates for Tank Systems with Metered Dispensing Systems

Leaking tank systems that have metered dispensing systems have mean and median leak rates that are nearly identical to the overall mean and median leak rates. (See Table 9-30.)

10. Mean and Median Leak Rates for Tank Systems that Were Self-Installed

Table 9-30 shows the mean and median leak rates for leaking tank systems which were installed by the establishment itself. Only a small number of tank systems in this category were tested, in view of which the mean and median rates may be regarded as not substantially different from the overall means and medians.

VI. STATISTICAL ASSOCIATIONS OF LEAK STATUS AND LEAK RATE WITH OTHER VARIABLES

A. Introduction

In this section we present the results of statistical correlations found between leak status and each of 49 possible explanatory variables. Similarly, results are reported for leak rate.

In addition, multivariate and logistic models were developed to identify significant predictor variables. Because these models resulted in rather low predictive power, they are considered preliminary, and further research is required. These models and their development are detailed in Appendix I.

B. Simple Correlations

No single explanatory variable, among the 49 examined, had a strong correlation with either leak status or leak rate -- i.e., no correlation coefficient was larger than .34 (Table 9-31). The

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Table 9-31. SIMPLE CORRELATION OF LEAK STATUS AND LEAK RATE WITH EXPLANATORY VARIABLES

Explanatory Variable	Meaning	Definition	Correlation(1) with Y1, Leak status (1 = Leak; 0 = No Leak)	Correlation(1) with Y2, Leak rate (gal/Hr), among leaking tanks(2)
X1	Gas Station	1 = Yes; 0 = No	-.08	-.06
X2	# Underground tanks	Number at facility	.12	.10
X3	Tank capacity	Gallons	.14	.34
X4	Average low fill level(3)	As fraction of tank capacity	-.05	-.07
$X5^2$	(Age of tank)^2	in (years)^2	.11	-.20
X6	Leaded gasoline	1 = yes; 0 = No	-.26	-.11
X7	Diesel fuel	1 = Yes; 0 = No	.24	-.08
X8	Aviation fuel	1 = Yes; 0 = No	.13	.07
X9	Gasohol	1 = Yes; 0 = No	-.07	0
X10	Other	1 = Yes; 0 = No	.08	.29
X11	Suction pump	1 = Yes; 0 = No	.003	-.12
X12	Depth buried	Inches from surface to top of tank	.10	-.006
X13	Water level	Inches from surface to water table(4)	-.15	-.005
X15	Tank tested	1 if tested after placed in service; 0 otherwise	.03	.01
X16	Years since test	Since most recent test	.06	-.21
X17	Tank material	1 = steel: 0 = fiberglass	.02	-.09
X18	Tank lined	1 = Yes; 0 = No	.07	.02
X19	Tank coated	1 = Yes; 0 = No	-.01	-.25
X20	Passive cathodic protection	1 = Yes; 0 = No	.10	.05
X21	Impressed current cath. protection	1 = Yes; 0 = No	0	0
X23	Other protection	1 = yes; 0 = No	-.08	0
X24	Previous tank leak	1 = Yes; 0 = No	-.05	-.04
X25	Previous line leak	1 = Yes; 0 = No	.05	.23
X26	Frequency of delivers	Number per year	-.05	-.003
X27	Sand fill	1 = Yes; 0 = No	.03	-.10
X28	Gravel fill	1 = Yes; 0 = No	.006	.16
X29	Concrete pad	1 = Yes; 0 = No	.07	-.09
X30	Packed earth pad	1 = Yes; 0 = No	.03	-.09
X31	Dist. to nearest tank or structure	(feet)	-.04	-.09

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[1] Pearson's correlation coefficient; Kendall's Tau-B was also calculated for all Y1 correlations and found to be the same for nearly every variable.

[2] Using data only from individual leaking tanks with quantifiable leaks.

[3] I.e., just before product is added.

[4] At time of test.

Table 9-31. SIMPLE CORRELATION OF LEAK STATUS AND LEAK RATE WITH EXPLANATORY VARIABLES (Continued)

Explanatory Variable	Meaning	Definition	Correlation(1) with Y1, Leak status (1 = Leak; 0 = No Leak)	Correlation(1) with Y2, Leak rate (gal/Hr), among leaking tanks(2)
X32	Interaction: age & material	(X5) (1-X17)	-.03	-.07
X33	Interaction: gasohol & material	X9 (1-X17)	0	0
X34	Permit to install	1 = Yes; 0 = No	.12	.17
X35	Permit to store	1 = Yes; 0 = No	.02	.09
X36	Average high fill level(6)	As fraction of tank capacity	-.06	-.09
XT3	Average fuel delivery	in gallons (to one tank)	.15	.23
XT4	Max. ever stored	gallons	.11	.29
XT18A	Attached to other tank	1 = Yes; 0 = No	.22	.24
XT19	Tank proximity to water table	1 = above; 2 = partially above; 3 = below; 4 = other	.13	.28
XT20	Manway with tank	1 = Yes; 0 = No	.19	.13
XT36	Not self-installed	1 = Yes; 0 = No	.12	.12
XB5	Remote gauge	1 = Yes; 0 = No	-.005	.05
XB19	Log of deliveries	1 = Yes; 0 = No	-.03	.002
XC7	Any abandoned tank(5)	1 = Yes; 0 = No	-.03	.03
XC8	# Abandoned tanks	(coded as zero if none)	.12	-.09
XF1A	Corrosion prevention equip./mat.	1 = Yes; 0 = No	-.02	-.12
XG2D	Trained to check pump	1 = Yes; 0 = No	.14	.24
XG2E	Trained to check line leaks	1 = Yes; 0 = No	.10	.18
XG2F	Trained to check leak prevention	1 = Yes; 0 = No	.10	.15
XG2G	Trained to check leak monitoring	1 = Yes; 0 = No	.15	.17

[5] At that facility.

[6] I.e., Just after product is delivered.

highest correlations with "leak status" (i.e., whether or not a tank is leaking) were found with the following variables:

Variable	Correlation Coefficient
Leaded gas	-0.26
Diesel fuel	+0.24
Tank manifolded	+0.22
Tank has manway	+0.19

Among leaking tank systems, the leak rate had stronger correlations. Eleven variables had a correlation coefficient larger than .20, as shown below:

Variable	Correlation Coefficient
Tank capacity	+0.34
Maximum ever stored	+0.29
Other fuel type	+0.29
Proximity to water table	+0.28
Tank coated	-0.25
Attached to other tank	+0.24
Trained to check pump	+0.24
Previous line leak	+0.23
Average fuel delivery (gal.)	+0.23
Years since tested	-0.21
$(\text{Age of tank})^2$	-0.20

The last variable in the list above is "age squared." It was used rather than "age" because of the non-linear relationship suggested by the plotted data. The sample size for most of these correlation coefficients is about 380. Due to missing data, some sample sizes are smaller, but all had a sample of 200 or more except X13 (N = 89), X16 (N = 72), and X18 (N = 173). Correlations with leak rate were calculated using all tanks that were tested for leaks. Somewhat different correlations might be found if only leaking tanks were included.

While this represents a considerable number of variables with non-trivial correlations with leak status and leak rate, none of the correlations would be considered strong and, therefore, no single variable will have a strong predictive ability.

Some variables of possible interest, such as soil characteristics, were not included because they were not collected in this study. However, data were included on the back fill material where used (sand, gravel, etc.).

C. Multiple Regression and Logistic Models

Multivariate models were developed to explain leak status and leak rate in terms of various predictor variables. Although some statistically significant relationships were found, the overall predictive ability of the models was low. The models could account for only 8 percent of the variance in leak status and 20 percent of the variance in leak rate. Therefore, further research in this area is still required. Appendix I describes the model development method and specifies which variables were statistically significant. Logistic and regression models identified several of the same variables as significant.

SECTION 10

INVENTORY RECONCILIATION TECHNIQUES

I. INTRODUCTION

Analysis of properly collected motor fuel inventory data offers the potential for an inexpensive, readily available approach to detecting tank-product losses, including those resulting from leaking tanks and piping. Inventory data is collected typically at the close of each day of operation by the tank establishment operator, records (1) volume of fuel in each tank as measured by metering stick or gauge, (2) delivery volumes, and (3) dispensing meter readings. From these measurements, the volume of fuel metered through a tank system's dispensers is reconciled with the physical measurement (based on stick readings and delivery volumes) of product gone from the tank.

Rarely are these two measurements of volume of daily through-put (physical versus dispensing meter) numerically equal, even when there has been no loss of product. Rather, they will show some variance either as an "overage" (a numerical excess of product in the tank) or an "underage" (a numerical loss of product). Some part of the daily variance will be due to random errors of measurement; however, inaccurate gauging and metering devices add to the variance, as do temperature-induced product shrinkage and expansion, vapor loss, theft, and leakage of product from (or of water into) the system. To further complicate interpretation of inventory reconciliation data, several of the above factors may contribute both to overages and underages.

There are currently available several commercially developed computerized models which can be used to identify and quantify factors contributing to daily inventory variances. These models are proprietary and, in any case, are much too sophisticated to be implemented and interpreted by a typical tank owner or operator. To monitor inventory using these models, a tank owner must contract for the services of one of the firms which has developed such a model. To provide tank owners and operators with a simple, inexpensive procedure for monitoring inventory, EPA has developed a procedure based on counts of the number of negative daily variances (underages) in successive monthly periods.[1] Because of its simplicity, the EPA method would not be expected to be as accurate as the more sophisticated modeling techniques. Tank tightness test data and inventory reconciliation data collected during two phases of the National Survey of Underground Motor Fuel Storage Tanks make possible a determination of the extent of agreement between tank tightness tests and the various methods of inventory reconciliation analysis, as well as the extent of agreement among the latter.

At the time the inventory analysis was conducted, the survey had provided complete, properly-collected inventory data on 855 tank systems. While this represents only the first portion of the inventory returns, the inventory data collection and editing effort resulted in 41 percent of the attempted cases providing usable data. Of these 855 tank systems, 511 were analyzed using the inventory reconciliation model developed by Warren Rogers

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[1] USEPA, Office of Toxic Substances, "More about Leaking Underground Storage Tanks: a Background Booklet for the Chemical Advisory," (October 1984).

Associates.[2] In addition, in a smaller study, 18 tank systems were analyzed by Entropy Limited.[3] Tightness test results were available for 189 of the 855 tanks for which usable inventory data was available. The EPA inventory analysis method was applicable, in modified form, to all 855 tanks; modification was required since the EPA method was intended for application to on-going monitoring programs and not to a single set of one-time inventory data.[4]

The present section provides an analysis of the extent of agreement of the above inventory reconciliation methods with one another and with tightness-test results, based on data collected in the survey. In addition, we report the results of a small quality control study in which the various inventory approaches were applied to a simulated set of inventory data for five tanks. Mathematical techniques were used to simulate various combinations of stick error, leakage and theft for the five tanks. The results of the inventory analyses were then compared with the true condition of the hypothetical tanks which in this case, of course, was known exactly.

II. METHODS AND DATA

The survey protocol called for the collection of 30 days of inventory data on each tank or manifolded tank system at the sampled establishments. Many respondents were unable to supply proper inventory data (see Appendix B for details), with the result that complete, usable data was obtained for only 855 tanks or manifolded tank systems. Of these tanks, 511 were analyzed by Warren Rogers Associates (WRA). Eighteen of the 511 tanks were also analyzed by Entropy Limited (EL). Of the 439 tank systems in the tightness test (TT) sample, 189 had usable inventory data. Table 10-1 shows the available sample sizes for all possible pairwise comparisons between methods.

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[2] Warren Rogers Associates, Inc., "Inventory Reconciliation System," (undated)

[3] Entropy Limited, "Precision Tank Inventory Control," (1984).

[4] USEPA, Office of Toxic Substances, "More about Leaking Underground Storage Tanks: a Background Booklet for the Chemical Advisory," (October 1984).

Table 10-1. Sample sizes for pairwise comparisons between methods

	EPA	WRA	EL	TT
EPA	855	511	18	189
WRA		511	17	106
EL			18	17
TT				439

The EPA-developed inventory analysis method is based on a simple count of the number of days for which the inventory reconciliation shows a negative variance, i.e., a numerical loss of product. An excess of days with negative variance over those with positive (or zero) variance may, under certain circumstances, be interpreted as a loss of product due to leakage or some other cause. The EPA method was developed and calibrated for application to an on-going monitoring program, in which cumulative month-by-month counts of negative variances would be compared with statistically-derived "action numbers" to determine whether there was evidence of a systematic deficit in inventory. Calculations indicated that the method would be effective in detecting even relatively small leaks over a sufficiently long period of monitoring, at least when reasonably good inventory records were kept.[5] The method was not intended for application to a one-time collection of 30 days inventory and, indeed, would not be expected to detect smaller leaks based on such a small data set. For the present comparisons, the method was modified and the following decision rule adopted: A tank system is declared leaking if the 30-day record exhibits 18 or more negative daily variances. Calculations detailed in Appendix E, indicate that this rule has approximately a five percent false-positive (or "false alarm") rate. That is, there is a five percent chance that a tank system which is not leaking and whose inventory record is subject only to random stick measurement error, would be declared leaking. This is consistent with the definition of a leak adopted for the tightness test procedure, see Section 8. However, the modified EPA inventory analysis method has significantly poorer detection capability than tightness testing, even in optimistic scenarios where the inventory record is subject only to stick measurement error and not to other sources of discrepancy, such as delivery errors. For example, the chance of detecting a leak of 0.1 gallons per hour (2.4 gallons per day) in a typical tank is approximately 17 percent, as opposed to 95 percent for tightness testing. A detection capability of 80 percent or greater was obtained using the EPA method for leaks in excess of 0.37 gallons per hour (8.9 gallons per day). By substantially increasing the number of days of inventory data, an 80 percent detection capability would be possible for smaller leaks.

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[5] David C. Cox, "Performance of the Chemical Advisory Inventory Analysis Method Under Various Scenarios," Report from Battelle Columbus Laboratories to EPA under Contract No. 68-01-6721 (April 1984)

Both the WRA and EL procedures are proprietary, so that details of the methodology and decision rules are available only in sketchy form. A description of the methods, based on literature provided by their developers, is given in Appendix E. The literature mentioned is partly promotional in nature. Claims made therein have not been investigated or verified by EPA, except to the extent reported here, so that no endorsement of the methods should be inferred. In order to place the WRA and EL methods on the same footing as the EPA and tightness test approaches, it is important that the false positive rate of the WRA and EL methods also be five percent. According to the developers of these methods, the inventory analysis results they have provided meet this requirement.

The WRA, EL and tightness test methods occasionally fail to produce a definite conclusion as to whether a tank system is leaking or not leaking. This occurs for the inventory methods whenever the data is excessively noisy due, for example, to large stick errors or very frequent deliveries. For tightness tests, various physical problems may lead to an indeterminate test result (see Section 8.) Table 10-2 presents a breakdown of the results for each method. It is reasonable that the tightness test procedure reports the largest percent leaking; this method should have the best detection capability. Likewise, the EPA procedure should have the lowest percent leaking, as it does. In the next section, we examine agreement between the methods, i.e., the extent to which they agree, not just on percent leaking but on which tank systems are leaking and which are not leaking.

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Table 10-2. Number and percent of tank systems judged to be leaking, judged not to be leaking, and providing inconclusive results for inventory methods and tightness testing

		Tank Systems Judged to be Leaking		Tank Systems Judged to be Tight		Tank Systems with Inconclusive Results	
Method	Sample Size	Number	Percent[1]	Number	Percent[1]	Number	Percent[1]
TT	439	152	35%	259	59%	28	6%
EPA	855	149	17%	706	83%	0	0%
WRA	511	160	31%	294	58%	57	11%
EL	18	4	22%	11	61%	3	17%

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[1] May differ from national estimates because survey sampling weights are not considered here.

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III. COMPARISON OF METHODS

In comparing two methods of deciding whether or not a tank system is leaking, one cannot focus simply on the degree of agreement between the predictions of the methods. To see why, consider two methods which give a correct prediction in 70 percent of cases. If the methods were completely independent, one would expect them to agree in 49 percent of cases, according to the rules of probability. This 49 percent represents the degree of agreement expected purely by chance and not due to any tendency for the methods to act in the same direction. In this example, agreement in significantly more than 49 percent of cases is required before one can conclude that the methods really are in substantial agreement. In this section, a statistic, K, is used to measure the agreement between methods above and beyond what is expected by chance.[6] The value $K = 0$ corresponds to purely chance agreement, while $K = 1$ means perfect agreement. Values of K between 0 and 1 may be interpreted on an ordinal scale, i.e., the larger K is, the better the agreement. Quantitative interpretation of K is more elusive, e.g., it is difficult to determine just how much agreement is represented by a value of, say, $K = 0.5$.

For each pairwise comparison between methods considered, we carry out a statistical test to determine whether there is sufficient evidence to conclude that K is positive, i.e., that there is more than chance agreement between the methods. In performing this test we have ignored inconclusive results for the various methods. We have also treated the data as if it were generated by a simple random sample of tank system, ignoring the

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[6] Yvonne M. M. Bishop, Stephen E. Fienberg and Paul W. Holland, "Discrete Multivariate Analysis: Theory and Practice," MIT Press, Cambridge, MA (1975)

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survey sample weights. Tables 10-3 through 10-5 present comparisons between the tightness test, WRA and EPA.

The two inventory methods show agreement with each other beyond what one would expect by chance alone. However, each inventory method exhibits only chance agreement with tightness test results. This conclusion should be regarded as tentative since the sample sizes for even the overall inventory -- tightness testing comparisons reported here are not very large. More detailed analyses of the agreement between the methods would not be statistically meaningful. It is, however, worth pointing out that the agreement does not appear to be improved even if we restrict attention to large leaks (as measured by tightness testing). For example, consider quantifiable leaks exceeding 4 gallons per day. The EPA procedure found 6 out of 23 (26%), for which a comparison was possible, to be leakers; WRA found 4 out of 7 (57%) leaking.

Statistically meaningful comparisons with the EL results are not possible because of the very small number of tanks evaluated by Entropy. However, the data confirm the above two findings in a general way. Inventory methods agree with one another but not with tightness test results. The extent to which inventory and tightness testing may be measuring differing phenomena, as is suggested by these results, is not clear. It is possible that certain measured leaks may not represent operational leaks. For example, leaks at the very top of the tank would occur in a tightness test, but might not occur in practice if the tank were never filled to the top. Likewise, a phenomenon such as theft may be reported as a leak by the inventory methods while the tank system tests tight. The resolution of this question will require more detailed analyses of the survey data and, possibly, collection of longer series (more than 30 days) of inventory data.

Table 10-3. Comparison of EPA Inventory Reconciliation Method with Warren Rogers Associates Inventory Reconciliation Method

		WRA		
		Number of tank systems judged to be leaking	Number of tank systems judged to be tight	Inconclusive
EPA	Number of tank systems judged to be leaking	61	19	10
	Number of tank systems judged to be tight	99	275	47

Percent agreement = 74%

K = 0.36 (STATISTICALLY SIGNIFICANT)

Table 10-4. Comparison of EPA Inventory Reconciliation Method with Tightness Testing

		TT		
		Number of tank systems judged to be leaking	Number of tank systems judged to be tight	Inconclusive
EPA	Number of tank systems judged to be leaking	13	22	1
	Number of tank systems judged to be tight	37	102	14

Percent agreement = 66%

K = 0.09 (NOT STATISTICALLY SIGNIFICANT)

Table 10-5. Comparison of Warren Rogers Associates Inventory Reconciliation Method with Tightness Testing

		TT		
		Number of tank systems judged to be leaking	Number of tank systems judged to be tight	Inconclusive
WRA	Number of tank systems judged to be leaking	9	28	0
	Number of tank systems judged to be tight	11	38	5
	Inconclusive	5	8	2

Percent agreement = 55%

K = 0.02 (NOT STATISTICALLY SIGNIFICANT)

IV. QUALITY CONTROL SAMPLES

A limited quality-control study of the 3 inventory reconciliation methods was conducted in order to compare performance on a data set for which the true leak status could be unequivocally determined. Inventory data for a total of 5 tanks at 2 sites was generated using mathematical techniques to simulate various combinations of stick error, leakage and theft. To maximize realism, actual tank conversion charts were used to simulate the effect of random measurement error due to sticking the tank. The simulated data was provided blind to WRA and EL. Table 10-6 shows the scenarios simulated. Table 10-7 shows the results of the inventory analyses. In addition to EPA, WRA and EL, we have added a simple t-test. The test is a standard t-test with 29 degrees of freedom based on the 30 daily variances in the inventory record. For consistency with the other inventory methods, the false positive rate of the test is set at 5 percent.

Site 1 represents clean inventory data. There is no noise in the record other than random measurement error due to sticking the tank. The EPA method and the t-test correctly predicted leak status for both tanks. WRA detected the leak but also classified the non-leaker as a leaker. EL correctely classified the non-leaker but reported the leaker as inconclusive (accurately estimating the true leak rate, however).

Site 2 represent a more difficult test of the inventory methods. Stick measurement error is unusually large. Moreover, both the random pattern of theft in tank 2 and the relatively small leak (3 gallons per day) in tank 3 would be expected to be difficult to detect by any inventory method based on only 30

Table 10-6. Simulated quality control inventory data

Site 1

Tank	Size	Product	Description
1	10,000	Reg. unleaded	5 gals/day leak
2	10,000	Reg. leaded	No leak, stick error only

Readings to nearest 1/2" on dipstick -- typical random measurement error of 14-19 gallons

Site 2

Tank	Size	Product	Description
1	6,000	Reg. leaded	Stick error only
2	6,000	Prem. unleaded	Theft 15-20 gallons on 9 days
3	10,000	Reg. unleaded	Leak, 3 gals/day

Readings to nearest 1" on dipstick -- typical random measurement error is 20-25 gallons for 6,000 gallon tanks, 35-40 gals for the 10,000 gallon tank

Table 10-7. Inventory analysis of quality control samples

Site	Tank	True Status	EPA		WRA			EL			t-TEST	
			LS	NEG	LS	LR	Comments	LS	LR	Comments	LS	LR
1	1	L - 5 gals/day σ = 17 gals	L	19	L	8.4	Delivery discrepancies (2), Unexplained gains or losses (4), Large stick errors (1).	?	4.6	Thermal shrinkage, vapor loss reported	L	6.6
1	2	NL - Stick error only σ = 17 gals	NL	15	L	2.8	Delivery discrepancies (2), Large stick errors (2)	NL	-	Thermal shrinkage, vapor loss reported	NL	-
2	1	NL - Stick error only σ = 22 gals	L	18	L	11.1	Unexplained gains and losses (3), Large stick errors (1). Average stick error low.				NL	-
2	2	NL - Theft on 9 days/30, approx. 17 gals σ = 22 gals	L	19	L	10.3	Unexplained gains and losses (6). Average stick error low.				L	10.0
2	3	L - 3 gals/day σ = 40 gals	NL	13	NL	-	Unexplained gains and losses (1). Data quality code = 2, meaning results explained by frequent deliveries??				NL	-

Legend: LS = Leak status
LR = Leak rate
L = Leak
NL = No leak
NEG = Number of negative daily variances
? = Inconclusive
σ = Standard deviation of stick measurement error

days' data. (The change of detecting the 3 gallons per day leak using the EPA method is only about 10%.) Both EPA and WRA predicted that the tight tank was leaking and that the leaker was not; both found the theft case to be a leak, thus successfully detecting the negative trend in the inventory, although attributing it to the wrong cause. The t-test correctly evaluated the non-leaker but also got the other two tanks wrong. A surprising feature of both sophisticated methods (WRA and EL) was a tendency to find effects in the data which were not in fact present. Thus WRA found numerous unexplained gains and losses, delivery discrepancies and large stick errors, while EL found theoretical shrinkage and vapor loss. These spurious findings apparently tended to obscure the true status of the tank systems. It should be pointed out, of course, that a method of analysis tailored to perform well on real-world, noisy data will of necessity be less than optimal for unusually clean data such as we have here. Moreover, the simulated data does not reflect the effects of factors such as location and time-of-year that may be very important to account for in real data analysis. The results reported here must be interpreted in this light.

V. CONCLUSIONS

We have compared a number of inventory reconciliation techniques, with each other and with the results of tank tightness tests, using data from the survey, as well as a small set of simulated inventory records. The sample sizes, especially for inventory vs. tightness test comparisons, were somewhat small. Finally, the data were analyzed as if they were generated by a simple random sampling technique, rather than the sampling procedures actually used in the survey. Thus, the conclusions reported here are tentative and require confirmation by further research. The major conclusions are:

- Results of inventory analysis methods and tightness tests exhibited only chance agreement;
- Inventory analysis methods agreed among themselves more than would be expected by chance; and
- On simulated data, all inventory methods were comparable in predictive power. However, the more sophisticated methods may have some tendency to "detect" noise in the data from effects that are not, in fact, present.

UNDERGROUND MOTOR FUEL STORAGE TANKS:

A NATIONAL SURVEY

VOL. II Appendices

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May 1, 1986

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APPENDIX A

SAMPLE DESIGN AND ESTIMATION OF WEIGHTS AND VARIANCES

I. TARGET UNIVERSE, OVERVIEW OF SAMPLE DESIGN

The target universe, or population of interest, for the Survey of Underground Storage Tanks consisted of all underground tanks which store motor fuel prior to dispensing it for use as fuel, with exceptions as noted below. For example, in the retail gasoline sector, this includes all underground tanks at service stations but excludes large holding tanks at a distributor. In sampling, we used a tank establishment, that is, a location with eligible tanks, as the sample unit. Once a given establishment was sampled, all its tanks were in the sample for the initial data collection phase. For the physical tank testing stage, a subsample of the sampled establishments was drawn, and all tanks at the subsampled establishments were physically tested. For purposes of list building, the target universe of establishments was defined as a number of segments, with certain exclusions as noted. The following types of establishments were identified as potentially having underground motor fuel storage tanks:

- Gasoline service stations;
- Other establishments almost certain to have underground storage tanks, including:
    - Transit and transportation fleets (such as taxi, trucking, and bus companies; auto and truck rental companies; railroads; and auto and truck dealers);
    - Marinas;

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  - Airports and other air transportation related industries; and
  - Golf courses and country clubs;
- Government fleet service pumps, including:
  - Federal;
  - State;
  - Local -- county, city, etc.; and
  - Military;
- Large companies with 20 or more employees in other (non fuel-related) industries which have private fleet service pumps; and
- Farms with underground motor fuel storage tanks.

Underground tanks containing motor fuels maintained by private homeowners and tanks for private fleets maintained by companies with fewer than 20 employees were excluded from the scope of this survey. They were not estimated to account for a large number of underground storage tanks. In addition, the cost necessary to screen out businesses and residences with no underground tanks was judged to be too great in comparison with the anticipated low addition to the total universe from these establishments.

A. Overview of Sample Design

The sample of establishments was drawn using a multi-stage cluster design. The continental U.S. was divided into six regions of interest. The sample was drawn to provide estimates both at the national and regional levels. The first stage of sampling was Primary Sampling Units (PSUs) consisting of counties or groups of contiguous counties with designated minimum estimated numbers of underground tank establishments. The sample of PSUs was allocated to the regions and drawn within region proportionally to their total estimated number of underground tank establishments. Thirty-four PSUs were drawn.

Within each selected PSU, three establishment frames were developed:

- Fuel tank establishments - consisting of gas stations, establishments in other fuel-related Standard Industrial Classification (SIC) groups, and government tank locations;
- Large establishments - consisting of all businesses with 20 or more employees not already listed as fuel tank establishments; and
- Farms - consisting of all farms.

A national sample was drawn from each frame. For large establishments and for farms, 600 establishments were selected from each frame. For the fuel tank establishments, a national sample size of 1,618 was allocated to the regions, and six regional samples were drawn. In each case, the establishment sample was drawn taking account of the PSU probabilities of selection in such a way that the establishment samples were self-weighting, nationally for the large establishments and farms, and by region for the fuel tank establishments.

Once the three samples were drawn, the large establishment and farm samples were telephone screened for the presence of underground tanks. All large establishments and farms which have underground fuel storage tanks became part of the field sample, as did cases which could not be resolved over the telephone. No substitutions were made for large establishments or farms with no underground fuel storage tanks. The fuel establishment tank sample consisted of establishments which were thought likely to have underground fuel storage tanks. Initial field work showed that this list actually produced about a 50 percent survey eligibility rate; that is, about half the sampled establishments sampled were still in business and had underground motor fuel storage tanks. Although lower than anticipated, this eligibility rate indicates that the coverage of the target universe by the selected SICs was probably quite good. In order to attain our target sample size of 800 eligible establishments, the initial sample sizes per region were doubled for the fuel establishment segment, for a total sample draw of 1,618 cases.

B. Definition of Regions; PSU Sample Design

Table A-1 lists the regions, giving the states included in each. They are shown on a map in Figure A-1. The PSU frame was developed for the entire continental U.S. as detailed in the following paragraphs.

For each county, the following counts were developed:

- Number of gas stations based on the 1981 County Business Patterns data (count for SIC 5541);
- Additional estimated number of gas stations allocated to counties within states on a population basis to bring the state totals up to the estimate provided by Versar to the EPA; and
- Total number of establishments in the selected other SICs (list in Table A-2) as given by the County Business Patterns data.

These three counts were summed for each county to form the estimated number of fuel tank establishments for the county.

The counties were grouped into initial PSUs by using the Westat Master PSU Frame developed on a population basis, which

Table A-1. Six regions for National Survey of Underground Fuel Storage Tanks

1 -- Northeast

- Maine
- New Hampshire
- Vermont
- Connecticut
- Massachusetts
- Rhode Island
- New York
- New Jersey
- Pensylvania
- Maryland
- Delaware
- Virginia
- West Virginia
- Washington, D. C.

2 -- Southeast

- Kentucky
- Tennessee
- Arkansas
- Louisiana
- Mississippi
- Alabama
- Georgia
- North Carolina
- South Carolina
- Florida

3 -- Midwest

- Wisconsin
- Minnesota
- Iowa
- Missouri
- Illinois
- Indiana
- Ohio
- Michigan

4 -- Central

- North Dakota
- South Dakota
- Nebraska
- Kansas
- Oklahoma
- Texas

5 -- Mountain

- Montana
- Wyoming
- Idaho
- Nevada
- Utah
- Colorado
- Arizona
- New Mexico

6 -- Pacific

- Washington
- Oregon
- California

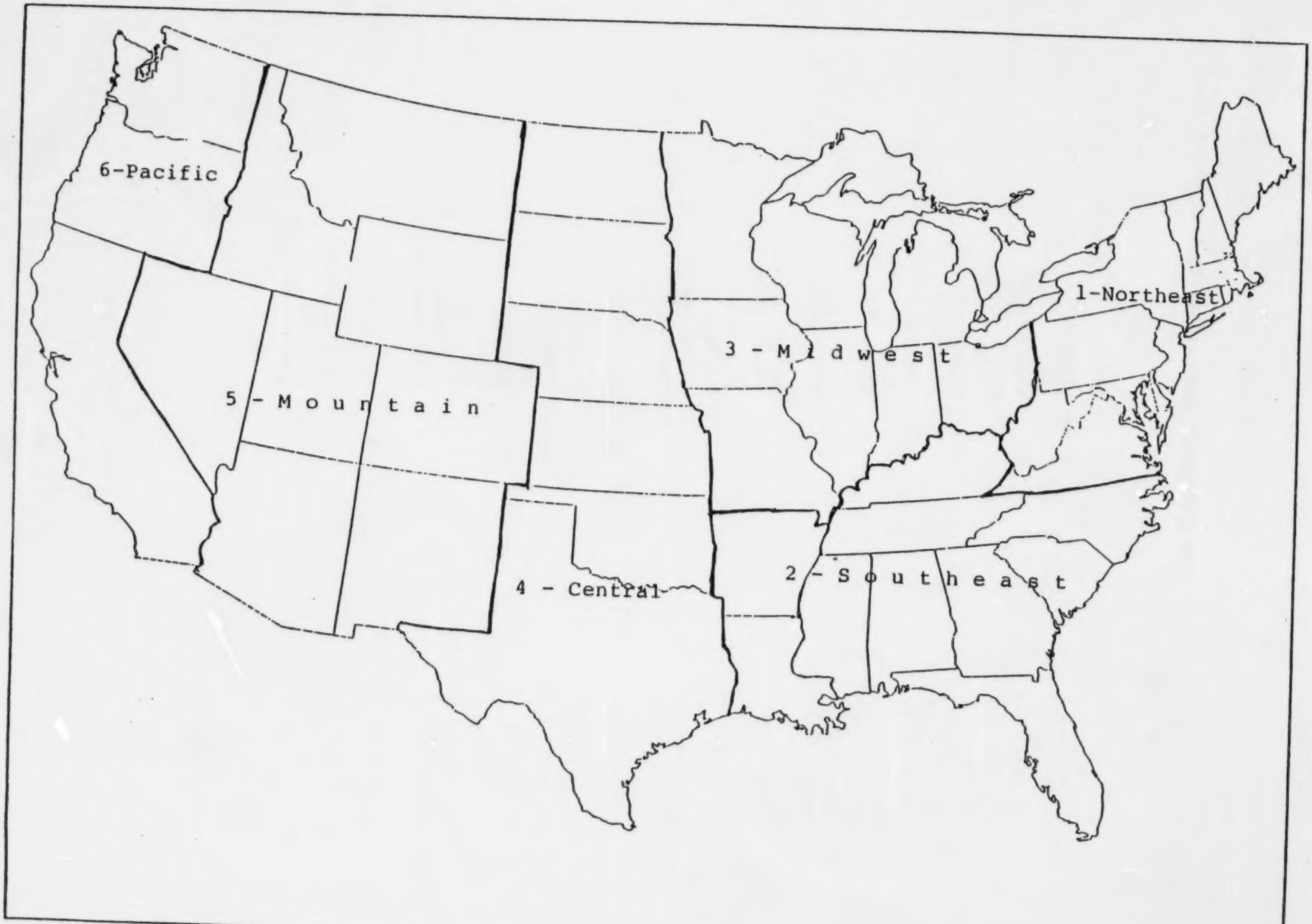
6-Pacific
5 - Mountain
4 - Central
3 - Midwest
2 - Southeast
1-Northeast

Figure A-1. Underground Storage Tank Survey Regions

Table A-2. Selected SIC codes for fuel tank establishment frame

SIC code	Description
4010	Railroads, switching and terminal companies
4110+	Local and suburban passenger transportation companies (includes airport transportation, ambulance and limousine services)
4121+	Taxicab companies
4131+	Intercity highway transportation services
4140+	Passenger transportation charter services (includes bus charter, rentals and tours)
4151	School bus companies
4170	Passenger transportation terminal and service facilities
4210+	Trucking companies
4231+	Motor freight terminals
4469A	Marinas
4511	Air transportation, certificated carriers
4521+	Aircraft charter, rental and leasing -- non-certificated carriers
4582A	Airports
4582B+	Aircraft maintenance services
4583	Airport terminal services
5511+	Auto and truck dealers (new and used)
5521+	Used car dealers
5541+	Gasoline service stations
7512+	Passenger car rental and leasing agencies
7513+	Truck rental and leasing agencies
7519+	Utility and house trailer rental agencies
7992+	Public golf courses
7997B+	Golf and country clubs

follows the PSUs used by the Census Bureau in designing the Current Population Survey. This initial list of PSUs was transformed to a final list by splitting PSUs which had large total counts into smaller sets of counties and combining PSUs with insufficient counts, resulting in a set of PSUs which were as small as possible while still containing a minimum number of fuel tank establishments.

Once the PSUs were defined, the sample of PSUs was drawn as follows. For each region, a target number of PSUs was established. This was six PSUs per region, except in Region 5 (Mountain) where four PSUs were drawn. Within each region, the PSUs were sorted by an urban versus rural designation, then by state, and finally by size (total estimated number of fuel tank establishments). The sample of PSUs was then drawn within each region on a probability proportional to size basis.

C. Tank Establishment Frames Within PSUs; Sample of Establishments

Once the thirty-four PSUs were selected, three establishment frames were built for each PSU. A sample was drawn from each frame, and eligible establishments in the three samples formed the sample of establishments.

The first frame was the fuel tank establishment frame. It consisted of establishments considered to be extremely likely to have underground fuel storage tanks. The frame was constructed from several sources. A list of business establishments with one of the target SICs (refer to Table A-2) in the selected counties was purchased from National Business Lists (NBL). This was supplemented by any establishments found to have one of the selected SICs in the large establishments list (see below).

Lists of Federal, state, and local government establishments in the sampled counties with underground fuel storage tanks were developed by extensive telephone contacts with government officials. In addition, a list of military establishments with underground fuel storage tanks was provided by the military to EPA. These lists were keypunched and added to the fuel tank establishment frame.

The sample of fuel tank establishments consisted of 1,618 establishments in the country (in order to achieve a target of 800 eligible establishments). Based on the regional totals of number of such establishments developed in the PSU frame-building effort, the total sample size was allocated to the six regions. Within each region, the establishments were sorted by PSU and SIC, and a self-weighting sample was drawn. Since the PSUs were sampled proportionately to the estimated number of establishments, this resulted in an approximately equal number of establishments per PSU within each region. There was not a precisely equal number per PSU for two reasons: the PSUs were sampled based on CBP counts and the establishments were sampled based on actual frame counts; and the PSU sample measure of size did not include an estimate for number of government establishments.

The second frame to be developed was the large establishments frame. This frame consisted of a list of business establishments in the sampled counties with 20 or more employees purchased from Dun's Marketing Identifiers (DMI). The establishments on this list with the fuel tank SICs (Table A-2) were clerically compared with NBL lists, county by county, to eliminate duplication between the two frames. Duplicates were deleted from the DMI list, and any establishment on the DMI list with one of these SICs not found on the NBL list were moved to the NBL list. The resulting DMI list was the frame for large establishments not in fuel tank SICs.

The sample of large establishments was drawn by first sorting the frame by region, PSU, and number of employees. Then a self-weighting sample of 600 establishments was drawn across the whole country. These establishments were contacted by telephone to determine whether they had underground fuel storage tanks. Those that did were part of the sample for initial data collection; no substitution was made for establishments with no tanks.

The third frame was farms. This was constructed by obtaining a list of all farms in the sampled counties from the U.S. Department of Agriculture, through EPA. The list included crop acreage for each farm. Any establishment on the DMI list with an agricultural SIC code was deleted from the DMI list and added to the farm frame if it did not already appear there.

The farm frame was sorted by region, PSU, and acreage. A national self-weighting sample of 600 farms was selected. These were screened by telephone to determine the presence of underground tanks. As with large establishments, no substitution was made for farms with no tanks.

II. PRIMARY SAMPLE UNIT (PSU) SAMPLE

This subsection discusses the first stage sample of Primary Sampling Units (PSUs). Appendix H discusses the sample of farms from PSU selection though the final sample of farms. Thus, this subsection and the following ones concentrate on the fuel establishments and large establishments, although some data on farms are included for completeness.

This subsection begins with a statistical description of the six survey regions based on data gathered in the construction of the Primary Sampling Unit (PSU) frame. It goes on to describe the PSU sampling process and concludes with a discussion of the sample of PSUs drawn.

A. Survey Regions

The six survey regions are defined in A-I, above, which includes a list of states in each region (Table A-1) and a map of the regions (Figure A-1). Here we describe the regions statistically in terms of characteristics important to the present study. Table A-3 gives several characteristics by region, both the amounts and the percent distributions.

The number of states and counties in each region is simply based on the definitions of the regions. The number of states ranged from three states in the Pacific Region (Region 6) to 14 states in the Northeast Region (Region 1). Alaska and Hawaii are not included, and the District of Columbia is counted as a state, making the total 49. In these 49 states there are 3,111 counties. The number per region ranges from a low of 133, again in the Pacific Region, to a high of 874 in the Southeast Region (Region 2).

The first step in constructing the PSU frame was to define PSUs, a process described in Subsection A-I. These consist of counties or groups of counties with a minimum estimated number of fuel establishments. The minimum was set separately for each region based on the expected number of establishments to be sampled per PSU in each region. The resulting PSU definition groups the 3,111 counties into 1,362 PSUs. The number per region

Table A-3. Statistical description of Underground Storage Tank Survey Regions [percent distribution in parentheses (4)]

Survey region	Number of states (Incl. DC)	Number of counties	Number of primary sampling units	1980 Population (1,000's) U.S. Census	Land area (sq. mi.)	Number of gas stations Versar report (1)	Number of facilities, selected other SICs 1981 CBP (2)	Sampling measure of size (3)	Number of large establishments (>20 empl.) 1981 CBP (2)	Number of farms, 1982 Census of Agriculture
1 Northeast	14	436	219	61,881 (27%)	238,400 (8%)	46,616 (24%)	34,829 (31%)	81,445 (27%)	157,843 (27%)	222,099 (10%)
2 Southeast	10	874	348	45,371 (20%)	466,678 (16%)	59,576 (31%)	19,403 (17%)	78,979 (26%)	108,367 (19%)	548,926 (24%)
3 Midwest	8	738	333	53,589 (24%)	448,419 (15%)	35,935 (19%)	27,124 (24%)	63,059 (21%)	138,742 (24%)	725,699 (32%)
4 Central	6	650	259	22,531 (10%)	634,346 (21%)	24,634 (13%)	11,738 (10%)	36,372 (12%)	61,756 (11%)	464,680 (21%)
5 Mountain	8	280	117	11,373 (5%)	855,193 (29%)	8,755 (5%)	5,273 (5%)	14,028 (5%)	29,144 (5%)	121,777 (5%)
6 Pacific	3	133	86	30,433 (14%)	318,994 (11%)	18,142 (9%)	13,843 (12%)	31,985 (10%)	87,461 (15%)	152,630 (7%)
Total	49	3,111	1,362	225,178	2,962,030	193,658	112,210	305,868	583,313	2,235,811

(1) Versar Corp. report to EPA, 1984

(2) County Business Patterns, 1981

(3) Sum of Gas Stations and Facilities with Other SICs

(4) Percent distributions may not add to 100% due to rounding.

ranges from a low of 86, again in the Pacific Region, to a high of 348 in the Southeast Region.

Two further statistics help set the stage for the survey in describing the regions: the number and percent of 1980 population in each region; and the square miles and percent of continental land area in each region. In terms of population, Regions 1-3 (the eastern block of regions) contain 27, 20 and 24 percent of the population, respectively, for a total of 71 percent of the population. Regions 4-6 have 10, 5 and 14 percent of the population, respectively. For land area the situation is reversed, though not as dramatic. Regions 1-3 contain 39 percent of the land area, while Regions 4-6 contain 61 percent.

The next three statistics form the basis of the PSU selection. The number of gas stations was estimated per state by Versar.[1] The distribution by region ranged from 5 percent in the Mountain Region (Region 5) to 31 percent in the Southeast Region (Region 2). Regions 1-3 contain an estimated 73 percent of the gas stations. The number of establishments with a Standard Industrial Classification (SIC) code among those selected as likely to have underground motor fuel storage tanks (see list in Table A-2) was found as counted in the 1981 County Business Patterns data.[2] Seventy-three percent of these other fuel establishments are in Regions 1-3. The percent by region ranges from a low, again in the Mountain Region, of 5 percent to a high of 31 percent in the Northeast Region. These two figures (gas stations and other fuel establishments) are summed to form the sampling measure of size. The distribution of gas stations and other fuel establishments follows that of the population.

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[1] Leaking Underground Storage Tanks Containing Engine Fuels, draft, March 1984, prepared by Versar, Inc. The gas station estimates were based on figures given in the 1983 Petroleum Marketing News Fact Book and include all retail outlets for branded gasoline.

[2] At the time of PSU sample selection, the 1982 CBP data were not yet available. They became available in time to use for final weights, as discussed in Subsection A-V.

Although the PSUs were sampled based on the number of fuel establishments, a sample of large establishments (with 20 or more employees) and of farms was also to be drawn from the sample PSUs. The region statistics show that large establishments follow the same general pattern as population and fuel establishments: 5 percent are found in the Mountain Region and 27 percent in the Northeast Region; Regions 1-3 contain 69 percent of the large establishments as reported by the 1981 County Business Patterns data. Farms are found mostly in Regions 2-4, which have 78 percent of farms as shown in the 1982 Census of Agriculture. Looking at the East versus West breakdown we have been considering, the Eastern regions (Regions 1-3) contain 67 percent of the farms.

In Table A-4 some of these statistics are shown for the urban/rural breakdown. Each PSU is designated as urban or rural according to whether it is part of a Statistical Metropolitan Area or not. The majority of PSUs and constituent counties are designed as rural (65 percent of PSUs, 77 percent of counties), but the majority of the fuel establishments plus gas stations are found in urban PSUs (69 percent). The large establishments are even more concentrated in urban PSUs, with 85 percent found there.

B. Sampled PSUs

The sample of PSUs was drawn as stated in Section A-I, using the number of fuel establishments as a sampling measure of size.

Table A-4. Summary of PSU sampling frame, urban versus rural PSUs (percent distributions in parentheses)

Urban/ Rural	Number of counties	Number of PSU's	Sampling measure of size (1)	Large establishments (>20 empl.) 1981 CBP (2)
Urban	722	482	212,164 (69%)	479,461 (85%)
Rural	2,389	880	93,704 (31%)	103,852 (15%)
Continental Total	3,111	1,362	305,868	583,313

(1) Number of gas stations (Versar) plus other fuel-related establishments (CBP)

(2) County Business Patterns data

Thirty-four PSUs were drawn -- six from each region, except Region 5 where four were drawn. Tables A-5 and A-6 give estimates of frame counts that would result from weighting the PSU sample data by inverse of the sampling probability. This gives an indication of how closely the sample reflects the frame from which it was drawn. Not surprisingly, the sampling measure of size (number of fuel establishments) tracks the population very closely, with the same percent distribution by region and only one percentage point different for the urban/rural breakdown. The large establishment counts are reproduced fairly well by the weighted sample. The percent distribution by region is within one or two percentage points of the population distribution, but the urban/rural breakdown is not as close. While 85 percent of large establishments were in the urban PSUs nationally, in the weighted sample PSUs, 79 percent are in the urban PSUs.

Tables A-7 and A-8 give unweighted counts for the sampled PSUs. In Table A-7, we see that the 34 PSUs are composed of 76 counties. The number of fuel establishments plus gas stations as estimated from the Versar and CBP sources for the sampled PSUs is 27,753, and the estimated number of large establishments is 74,768. Table A-8 shows that 11 of the 34 PSUs are rural, with 36 of the 76 counties. The rural PSUs tend to have more counties in order to contain the minimum number of fuel establishments. The vast majority of both fuel and large establishments in the sampled PSUs are in the urban PSUs (95 and 98 percent, respectively). In the sample, one county, Los Angeles, was large enough to be self-representing. This PSU accounts for the large unweighted counts for Region 6 (Pacific) throughout the tables.

Overall, the PSU universe appears to be well reflected in the sample of PSUs. Figure A-2 shows the location of the sampled PSUs to indicate their geographic representation, as well. The

Table A-5. Weighted data from sampled PSUs, region summary (percent distributions in parentheses

Survey region	Number of counties	Number of PSU's	Sampling measure of size (1)	Large establishments (>20 empl.) 1981 CBP (2)
1 Northeast	561	210	81,364 (27%)	148,906 (25%)
2 Southeast	635	341	78,974 (26%)	123,360 (21%)
3 Midwest	912	328	63,139 (21%)	135,842 (23%)
4 Central	1,660	327	36,374 (12%)	57,475 (10%)
5 Mountain	344	120	14,030 (5%)	29,440 (5%)
6 Pacific	114	73	31,988 (10%)	89,358 (15%)
Total	4,227	1,399	305,868	584,381

(1) Gas stations plus other fuel establishments

(2) County Business Patterns data, 1981

(3) Percentages may not add to 100 due to rounding.

Table A-6. Weighted data from sampled PSUs, urban versus rural summary (percent distribution in parentheses)

Urban/ Rural	Number of counties	Number of PSU's	Sampling measure of size (1)	Large establishments (>20 empl.) 1981 CBP (2)
Urban	613	364	207,558 (68%)	462,468 (79%)
Rural	3,614	1,036	98,309 (32%)	121,913 (21%)
Total	4,227	1,399	305,867	584,381

(1) Gas stations plus other fuel-related establishments

(2) County Business Patterns data

Table A-7. Unweighted PSU sample data, region summary

Survey region	Number of counties	Number of PSU's	Sampling measure of size (1)	Large establishments (>20 empl.) 1981 CBP (2)
1 Northeast	13	6	5,453	9,051
2 Southeast	12	6	3,321	5,888
3 Midwest	14	6	2,317	6,555
4 Central	19	6	5,074	12,573
5 Mountain	10	4	1,144	3,058
6 Pacific	8	6	10,444	37,643
Total	76	34	27,753	74,768

(1) Gas stations plus other fuel-related establishments

(2) County Business Patterns data

Table A-8. Unweighted PSU sample data, urban versus rural summary

Urban/ Rural	Number of counties	Number of PSU's	Sampling measure of size (1)	Large establishments (>20 empl.) 1981 CBP (2)
Urban	40	23	26,627	73,305
Rural	36	11	1,126	1,463
Continental Total al	76	34	27,753	74,768

(1) Gas stations plus other fuel-related establishments

(2) County Business Patterns data

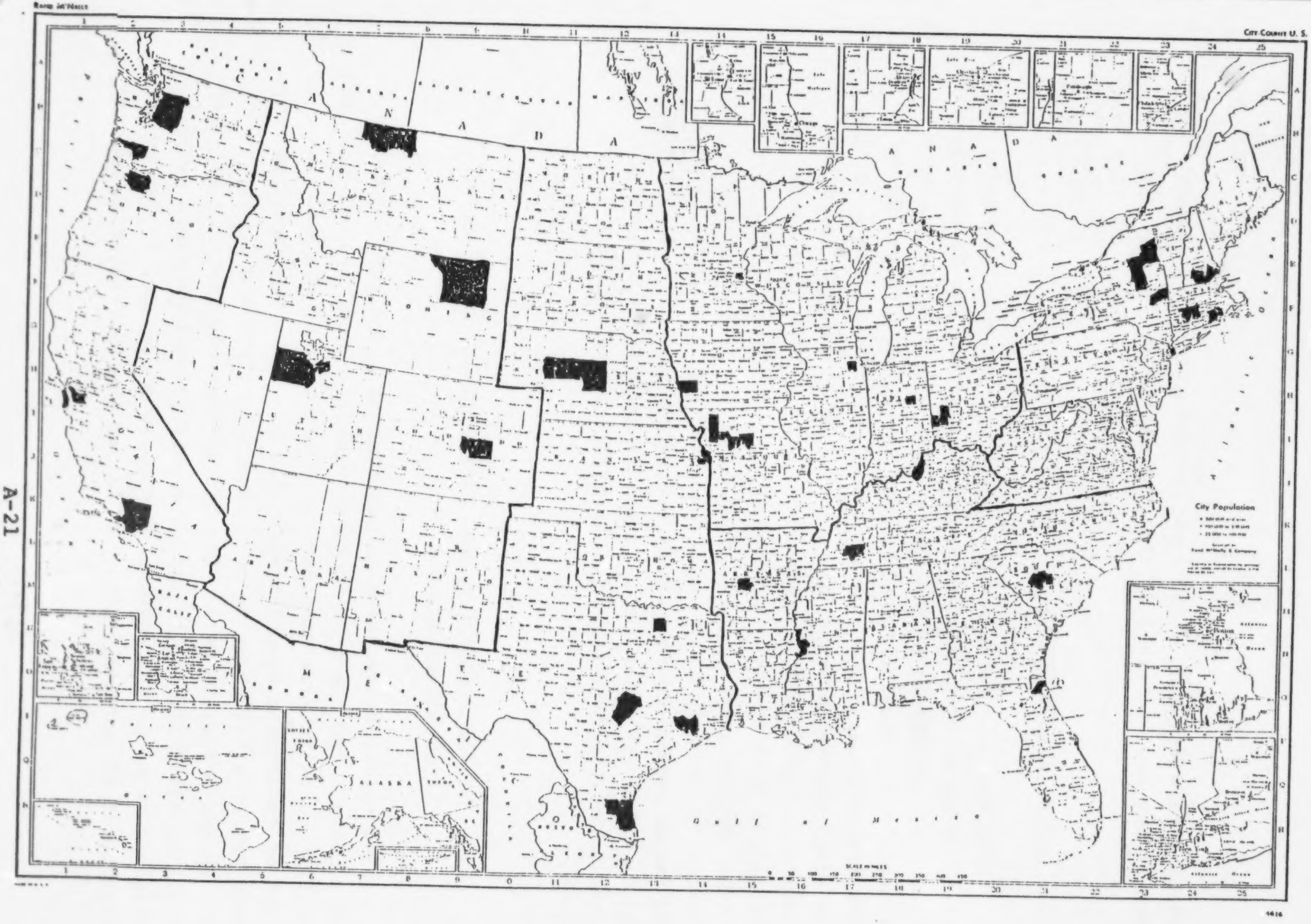

Figure A-2. Sample PSU locations

establishment sampling frame construction and establishment sample draw are described in the next section.

III. ESTABLISHMENT SAMPLE

Once the 34 PSUs were drawn, lists of all establishments in the three sampling sectors were constructed for the 76 counties which comprise the 34 PSUs. These lists are known as sampling frames. The initial sample of 2,818 establishments was drawn from these frames and screened for eligibility. Since so little was known initially about what type of establishment would have underground motor fuel storage tanks, the eligibility rates themselves were an early finding of the survey. The 896 eligible establishments form the final sample for the survey. This process is described in detail below for the fuel establishment and large establishment sectors (which account for 2,218 initial sample cases and 876 eligible cases). Appendix H reviews the process for the farm sector (600 initial cases and 20 eligible cases).

A. Sample Frames for Fuel-Related Establishments and Large Establishments

The sample frames were constructed as described in Section A-I, above. For the fuel-related establishments, several methods of list-building were combined to result in a single list. A list of government agencies with eligible tanks was developed for each PSU by a telephone search. Federal, state and local government officials were contacted to generate lists of all such civilian agencies, and a list of military establishments with eligible tanks in the sampled counties was provided to EPA by the Department of Defense (DoD). A list of the fuel-related business establishments (gas stations and other industries, see list in Table A-2) was purchased from National Business Lists (NBL) and supplemented by any additional establishments with one of the selected SICs that appeared on the purchased DMI list of large establishments. The constructed government and military lists were appended to the purchased establishment list to form the fuel establishment sampling frame.

The large establishment sampling frame was purchased from Dun and Bradstreet's list of business establishments, the Dunn's Market Identifiers (DMI). This list source is more expensive than NBL but was required since it contains the number of employees for each establishment, which NBL does not. A list of all establishments in the sampled counties with 20 or more employees was purchased. The establishments on this list with any of the fuel-related SIC codes were selected from the large establishment frame and printed out. They were clerically compared with the fuel establishment frame, county by county, and any such establishment not already on the fuel establishment frame was added to it.

Table A-9 shows the resulting frame counts by survey region for these two frames. The counts show fairly good (by no means perfect) agreement with the counts in Table A-7, based on CBP and Versar data. For large establishments not in fuel-related industries, the frame count is about 10 percent lower than the CBP count. Region 6 (Pacific) shows a higher percent deficit, about 15 percent, and also the bulk of the amount, 5,000 cases. For the fuel establishment sample, the total measure of size in Table A-7 (27,753 establishments) does not include any allowance for government and military cases, of which there were 3,139 on the frame. Subtracting these from the frame total leaves 30,583 establishments, or about 10 percent more than the sampling measure of size. Table A-10 shows the frame counts broken down

Table A-9. Number of establishments on the frames for 34 sampled PSUs (unweighted), by survey region

Survey region	Fuel establishment frame count	Large, non-fuel establishment (≥ 20 employees) frame count
1 Northeast	5,403	8,472
2 Southeast	3,023	4,811
3 Midwest	3,355	6,193
4 Central	6,027	13,227
5 Mountain	1,650	2,698
6 Pacific	14,264	32,677
Total	33,722	68,078

Table A-10. Number of establishments on the frames for sampled PSUs (unweighted), by urban versus rural

Type of PSU	Fuel establishment frame count	Large, non-fuel establishment (≥ 20 employees) frame count
Urban	33,208	66,935
Rural	1,723	1,143
Total	34,931	68,078

by urban versus rural PSUs, which agrees well with the breakdown found in Table A-8.

B. Establishment Sample Draw

As described in Section A-I, above, the fuel establishment and large establishment samples were drawn separately.

For the large establishments, a single national self weighting sample of 600 establishments was drawn. The frame was sorted by PSU and by number of employees within PSU. Each case was given a measure of size in inverse proportion to the sampling probability of the PSU it was in. A systematic sample (based on a random start) of 600 establishments was drawn using probability proportional to this measure of size.

The fuel establishment sample was drawn one region at a time so that sampling could begin before all frames were completed. The target number of 800 eligible establishments was allocated to the six survey regions based on their sampling measure of size. Based on early results for eligibility rates of government and gas station establishments, and based on the relative proportion of the frame in each region that fell into these two categories, the target number of eligibles was inflated to an allocated initial sample size for each region. The net result was an approximate doubling of the sample size. The detailed figures appear in Table A-11.

Table A-11. Target sample size, by region, for fuel establishment sample

Survey region	Target number of eligible establishments	Allocated size for sample draw
1 Northeast	213	449
2 Southeast	206	415
3 Midwest	165	325
4 Central	95	194
5 Mountain	37	75
6 Pacific	84	160
Total	800	1,618

C. Eligibility Rates for Fuel and Large Establishment Sample

Once the samples were drawn, they were screened for eligibility. Table A-12 shows the initial sample draw and number of eligible cases, by region, for both samples. There were several possible reasons for a sampled establishment being ruled out of the scope of the survey. Some establishments were found to be not actually located in the sampled county (48 cases for these two samples), out of business (85 cases), or ineligible for other similar reasons (22 cases). Six were duplicates of another sampled listing. Of establishments found to be in the survey counties and in business, 97 had only abandoned tanks and 1,084 had no underground storage tanks, or stored only non-motor fuel substances, leaving 876 eligible establishments.

Table A-13 shows weighted eligibility rates by type of establishment for the survey regions and overall. It shows that about 80 percent of sampled gas stations were survey-eligible. Ineligible gas stations were generally out of business. Eighty percent of government and military were eligible. Some had been mistakenly included on the frame. Ineligible government cases were generally out of area or storing non-motor fuel substances. The other fuel-related industries category shows about one-quarter eligible. Here, the out of business rates were lower than for gas stations, and most ineligible cases had abandoned tanks or no tanks. For large establishments the overall eligibility rate was 13 percent. Almost all of the ineligibles in this sample were establishments which simply had no tanks.

These varying eligibility rates show that although underground motor fuel storage tanks are concentrated in certain industries, they occur in establishments in a broad range of industries.

Table A-12. Sample eligibility, by region, unweighted counts of sampled cases

Survey region	Fuel establishments		Large establishments	
	Total sample draw[1]	Number of eligible establishments	Total sample draw	Number of eligible establishments
1 Northeast	447	225	158	21
2 Southeast	413	197	116	18
3 Midwest	324	161	142	13
4 Central	193	92	68	7
5 Mountain	75	42	29	4
6 Pacific	160	83	87	13
Total	1,612	800	600	76

[1] 1,618 cases were drawn, but 6 were found to be duplicates during the screening process.

Table A-13. Weighted eligibility rates (percent eligible), by region and type of establishment

Survey region	Type of establishment				
	Gas stations (%)	Other fuel-related industries (%)	Government and military (%)	Fuel establishment sample combined (%)	Large establishments (%)
1 Northeast	83	27	70	53	13
2 Southeast	81	19	85	51	16
3 Midwest	83	21	81	53	9
4 Central	79	23	89	54	10
5 Mountain	84	27	100	60	14
6 Pacific	86	30	82	59	15
Total	83	24	80	54	13

IV. SUBSAMPLE OF ESTABLISHMENTS FOR TANK TIGHTNESS TESTS

The eligible sampled establishments had approximately 2,000 underground motor fuel storage tanks or manifold systems. A subsample was drawn for physical tank testing. For the survey at large, the target number of tank tests was 500. Fifty were set aside for farms (during the planning stage, it was not known how many farm tanks would be found), leaving 450 tank tests for the subsample of fuel-related and large establishments.

At the time the subsample was drawn, it was assumed that a manifolded system of two or more tanks connected by piping would always be physically tested as one unit and therefore would count as one test. During the process of doing the testing it was found that, in fact, some systems were relatively simple to break apart for testing, and this was done where possible. In this section, we count tanks or manifolded systems; but in the sections reporting on tightness tests, the counts of individuals tanks or of separate tests are generally given.

Table A-14 shows the allocation of the 450 tank tests by survey region. This allocation is the estimated number of tanks or tank systems to be tested for each category; some variation occurred in the final sample since establishments rather than tanks were the sampling unit. For the farms, the number of tank tests depended on what was found during the interviewing and tank test scheduling.

The allocation was made as follows. Of the 450 tank tests, 40 were allocated to Region 5 to assure a minimum sample size for that region. The remaining 410 tank tests were allocated to Survey Regions 1-4 and 6 in approximately the same proportion as

Table A-14. Subsampling establishments for tank tightness testing (fuel and large establishments combined

Survey region	List of eligible establishments		Subsample for tank tightness testing		
	Number of eligible establishments (at time of subsampling)	Number of tank systems[1] at eligible establishments	Target Number of tank systems[1] to subsample	Number of establishments subsampled	Number of tank systems[1] at subsampled establishments
1 Northeast	248	587	115	51	112
2 Southeast	214	544	110	47	111
3 Midwest	175	426	90	38	86
4 Central	100	231	50	23	52
5 Mountain	46	116	40	17	43
6 Pacific	96	207	45	22	46
Total	879	2,111	450	198	450

[1] In allocating and drawing the subsample of establishments for tightness testing, a manifolded tank system was counted as one unit. Some such systems were separated for physical testing.

the fuel establishment sample allocation. Allocating the sample in advance permitted us to draw the sample on a region by region basis as the final eligibility results came in from the field interview phase of the survey.

For each region, a sampling frame was created, containing eligible fuel and large establishments at which tanks were found (including establishments that refused to be interviewed). The frame construction waited until all cases had reached a final status and preferably had a known number of tanks or manifolded systems. The frame contained the establishment ID, the number of tanks or manifolded systems, and the establishment sampling weight. This list was then sorted by number of tanks, then by PSU (from ID), and then by fuel establishment versus large establishment (also part of ID). The weights were cumulated down the entire list. The number of facilities to select, M_j, was based on the allocated number of tanks, N_j, and the weighted average number of tanks per establishment, T_j, as shown in the following equation:

$$M_j = N_j/T_j$$

The sampling interval, SI_j, was the grand total of the weights divided by M_j (M_j was not rounded). The sample was drawn in systematic fashion, beginning with a random start between 0 and SI_j. The establishments selected in each survey region have a total number of tanks or manifolded systems close to N_j (see Table A-14). Within each survey region, all underground fuel storage tanks or manifolded systems have an equal probability of selection for physical tightness testing.

V. FINAL SAMPLE WEIGHTS

A. Questionnaire Weights for Business and Government Establishments

1. Other Fuel-Related SICs (Other Than Gas Stations)

The final questionnaire weights for establishments sampled with fuel-related SICs other than gas stations were based on a ratio adjustment of the initial sample weights for all such screened establishments to 1982 CBP counts of these SICS, followed by a nonresponse adjustment among the eligible other fuel-related establishments to account for the few nonrespondents. The adjustments were made by survey region. The ratio adjustment served to put the initial sample on a known basis, the number of establishments with one of the fuel-related SICs in each region. Then the eligible cases weight up to an estimate of the number of such establishments with eligible tanks, by region. The nonresponse adjustment assures that the weighted results based on questionnaires received will equal the estimates based on screening results.

2. Gas Stations (SIC 5541)

The gas stations were weighted in the same way as other fuel-related SICs. First, the initial sample was ratio-adjusted by region to CBP totals for gas stations. The eligible cases then weight up to an estimate of the number of gas stations with eligible tanks, by region. A nonresponse adjustment again assures that the weighted results based on questionnaires received will equal the estimates based on screening.

3. Other Industries (Establishments With 20 or More Employees)

The sample sector of establishments with 20 or more employees in industries not otherwise sampled (the large establishments) was weighted the same way as the gas stations and other fuel-related industries. The CBP totals of establishments of this size in all but the selected fuel-related SICs (which include SIC 5541, gas stations) were used for a region by region ratio adjustment of the initial sample. The weighted eligible large establishments then estimate the number of such establishments with eligible tanks in the country, by region. Since all eligible large establishments participated in the interview phase of the survey, no nonresponse adjustment was needed.

Table A-15 shows the totals based on 1982 County Business Patterns data which were used as the fixed totals the initial sample weights were adjusted to sum to.

4. Government Agencies

No national statistics are currently available to estimate the number of individual government agencies with underground motor fuel storage tanks, which is the universe our frame was built to cover. Therefore, no ratio adjustments can be made. Nonresponse adjustments were made to account for the small amount of nonresponse.

Table A-15. Known totals from 1982 County Business Patterns data base used for ratio adjustment

Survey region	Type of establishment		
	Gas station (SIC = 5541)	Other selected fuel-related industries	Large establishments ($\geq$ 20 employees) not in selected industries
1 Northeast	28,212	42,173	158,320
2 Southeast	22,623	29,825	109,137
3 Midwest	27,551	37,391	131,769
4 Central	12,473	17,786	67,150
5 Mountain	6,100	7,881	30,129
6 Pacific	13,840	18,565	84,998
Total	110,799	153,621	581,503

B. Physical Test Result Weights for Business and Government Establishments

After calculating final questionnaire weights for all responding establishments as described above, the sampling weights for establishments chosen for physical testing were adjusted to sum to the estimated totals for four establishment types (government, gas station, other fuel-related, and other industry) by region. This adjustment was made by an iterative rating procedure in which the weights were adjusted first to regional totals, then to establishment type totals, then readjusted to regional totals, and so forth, until no further adjustment was needed. This took five and a half iterations to achieve.

A final adjustment was made for tank test result weights. If all selected tanks had been tested, the weight for an individual tank or tank system test would be equal to the establishment physical test weight. However, some tanks were not tested. Thus a "tank nonresponse" adjustment was made to the tank/tank system weights to account for the untested tanks. A single tank counted once (added its weight) in the count of tanks selected and once in the count of tanks selected. A manifolded tank system which was not tested counted once for each tank in the count of tanks selected. A manifolded tank system which was broken apart and tested as separate tanks also counted once for each tank in each count. A manifolded tank system which was tested as one system counted once for each tank in the count of tanks selected and once for each tank in the count of tanks tested. The ratio of the weighted count of tanks selected to the weighted count of tanks tested was used to form the final adjustment to tank weights. This was done over the sample as a whole rather than by region.

C. Farm Questionnaire and Physical Test Weights

Due to the distribution of farms within the survey regions (both overall and in our sample) and the low yield of eligible farms from the screening, for weighting and any regional analysis purposes the survey regions have been consolidated into three areas for farms (see Appendix H). These are:

- East (combines Northeast and Southeast Survey Regions);
- Midwest; and
- West of the Mississippi (combines Central, Mountain and Pacific Survey Regions.

Total counts of farms for these areas were obtained from the 1982 Census of Agriculture and used to form ratio adjustments for eligible farms. Due to one refusal among farms, a nonresponse adjustment was also made.

Since so few farm tanks were tightness tested, no weighted estimates will be presented for that data, and hence final weights were not prepared for physical test results for farm tanks.

VI. VARIANCE ESTIMATION

A. Jackknife Approach to Variance Estimation

In a complex survey such as this one, it is difficult or impossible to estimate the variance of survey estimates directly from algebraic formulas. An alternative approach often used, and adopted for this survey, is the so-called jackknife method of variance estimation through replication. The idea behind the method is to draw a collection of subsets of the sample, called replicates, and use the subsets to form national estimates of the statistic whose sampling variance is being estimated. The variability among these estimates is used to estimate the sampling variance of the estimate based on the full sample. [See Sampling Techniques, 3rd Edition, W.B. Cochran, J. Wiley & Sons, 1977 for a brief discussion of the principles of this method.]

B. Replicate Formation

To form the replicates, the sampled PSUs were paired and one PSU dropped from each pair in turn. Since there were 34 PSUs, there were 17 pairs and 17 replicates. The pairs were formed as follows. Thirty-four PSUs were drawn in six survey regions. Except for one certainty PSU in Region 6, they were paired into strata in straightforward fashion -- PSU 1 with 2, PSU 3 with 4, and so on. Region 6 required some special consideration. The sample in the region consisted of PSUs 29 through 34, with PSU 31 being a certainty PSU. PSUs 29 and 30 were paired. Establishments in PSU 31 were separated into "odds" and "evens" and these sets were treated as a pair of PSUs. This left PSUs 32, 33, and 34 to consider. These three PSUs were grouped into one stratum; PSU 33 was randomly paired with 32, giving the paired PSUs 3/4's their initial weight; and PSU 34 was given 3/2's its initial weight. Then either the singleton or the paired PSUs are randomly selected to be dropped for one replicate.

The resulting strata and random selection of which PSU to drop from each stratum, in turn, to form a replicate (17 replicates in all) are shown in Table A-16.

Table A-16. Definition of strata and replicates for jackknife estimation of variance

Stratum	PSU 1	PSU 2	PSU to drop
1	1	2	1
2	3	4	4
3	5	6	6
4	7	8	8
5	9	10	9
6	11	12	12
7	13	14	14
8	15	16	16
9	17	18	17
10	19	20	19
11	21	22	22
12	23	24	23
13	25	26	26
14	27	28	27
15	29	30	29
16	31, odds	31, evens	31, odds
17	(32 & 33) (3/4's)	34 (3/2's)	(32 & 33)

C. Jackknife Replicate Weights and Variance Estimates

Seventeen replicates were formed by dropping a randomly selected PSU from each stratum, in turn. Weights were calculated for each replicate as follows. As an initial sampling weight for the replicate, establishments at the selected PSU of a pair were assigned twice their initial weight, while establishments in the dropped PSU were assigned zero. Establishments in all other PSUs kept their initial sampling weight. Then the ratio adjustment to CBP totals by industry type and region and the nonresponse adjustment by the same categories were done as described above for the full sample final weights. For tank test replicate weights, the subsampled establishments in the replicate had their weights adjusted by raking to the replicate total by region and industry type, and replicate tank test nonresponse adjustments were made. Repeating all steps of final weight adjustment in calculating the replicate weights ensures that the variance estimates will reflect the impact of weight adjustments on the variance.

Subscripting the 17 replicates by $r = 1 \ldots, 17$, the variance of a national estimate, $\hat{X}$, of a statistic X is given by:

$$\hat{S}_X^2 = \sum_{r=1}^{17} (\hat{X}_{(r)} - \hat{X})^2$$

where $\hat{X}_{(r)}$ is the estimate based on the $r^{\underline{th}}$ replicate. The flexibility of this method of variance estimation can be realized by noting that the statistic X could be not only a total (such as number of establishments with tanks) or a proportion (percent of all tanks that leak) but any statistic that can be estimated from the full sample and from each replicate in turn.

APPENDIX B

SURVEY PROCEDURES AND ELIGIBILITY AND RESPONSE RATES

I. IN-PERSON INTERVIEW PRETEST

In July and October of 1984, survey packages (including introductory letter, questionnaire, general instruction booklets, and inventory forms) were mailed to a pretest group of 10 establishments which were previously determined to have underground storage tanks in use. They were selected through liaison with local government and military officials rather than by random sampling or from developed survey listings. The July pretest group consisted of seven "fuel-related" establishments and the October group included three military installations. Using government-operated establishments in the pretest allowed us to prepare for problems not normally encountered in non-government situations. The purpose of the pretest was to evaluate the format and wordings of the questions in the interview for clarity and administerability; to determine the length of administration time for the interview; and to assess specific and overall response to the flow of the interview and individual items in the interview. In addition, several on-site procedures were tested including meter testing, tank sticking, site diagraming and soil sampling. Several revisions to materials and adjustments to on-site procedures were made prior to the field period. No results from the pretest are included in the final estimates of the survey.

II. WESTAT TELEPHONE PRESCREENING AND LIST CONSTRUCTION PROCEDURES

Since lists of establishments with underground motor fuel storage tanks do not exist, it was necessary to develop establishment frame lists for each of the 34 PSUs. As described in detail in Appendix A, the universe of all establishments with underground motor fuel storage tanks was divided into three segments: the fuel-related establishments, large establishments (with more than 20 employees), and farms. Lists of fuel-related establishments, large establishments and farms were purchased or obtained for the 34 PSUs in the survey. Since a list of government establishments and locations was not available, a telephone list construction procedure (described in Section B-II.B below) was used to construct government tank establishments lists in the 34 PSUs. In the 34 PSUs a sample of 1,618 fuel-related establishments (including government and military establishments), 600 large establishments, and 600 farms was drawn to be surveyed. Since eligibility rates were expected to be low (less than 50%) telephone screening procedures were implemented using the Westat Research Telephone Center in order to determine which farms and large establishments were "eligible" (had underground storage tanks) for the survey. (Fuel establishments, including government and military establishments were screened in the field.)

A. Government Tank Establishment List Construction

Because there is no central listing source for government establishments with underground motor fuel storage tanks, federal, state, county, and city lists were developed using extensive telephone research. Initial contacts with officials at different government levels (i.e., state and county Fire Marshall's Office, Public Works Department, local Police Department) provided the telephone interviewer with the location of underground storage tanks or referrals to other contacts who could furnish information on underground storage tank locations. Hard-copy listings were accepted by mail if the data was too extensive to be given over the phone. After all leads were exhausted, using a minimum number of calls, and the lists were determined to be complete. They were then added in as part of the fuel-establishment sample frame.

B. Farm and Large Establishment Screening

Using the farm and large establishment sample lists, telephone interviewers contacted the owner or operator of the establishment and asked whether the farm or business had any underground storage tanks in use to store motor fuel. For those establishments which were eligible, a contact name was obtained to assist the field interviewer. All establishments that could not be located by phone (19%) or refused the screening interview (1%), were included in the field screening efforts. All but two percent of the farms and large establishment that could not be located or screened by telephone were located and screened in the field screening effort.

III. UST SURVEY MAILOUT

The mailout for the UST Survey began on November 26, 1984 with survey Region 6 (West coast) and continued in phases working through Region 4 (Southwest), then Region 2 (Southeast), Region 1

(Northeast) and Region 3 (central U.S.). (See survey region map in Figure B-1.) The last phase of the mailout was completed on May 3, 1985, with packages being sent to Region 5 (Midwest). Survey packages were sent certified mail to a sample of 1,965 establishments. Included in this sample were those farms and large establishments which could not be located through the initial Westat telephone screening. Survey packages were mailed according to the schedule of the field interviewers, so that the respondents received the survey materials approximately two weeks prior to the interviewer's arrival at the site. The purpose of the survey mailout package was to allow the respondent time to prepare for the in-person interview.

Because the packages were sent certified mail, the date the package was received and the name of the recipient was available for the interviewer. The field interviewer used this information to trace those establishments which could not be located by phone. Each day, certified mail receipt cards returned were keyed into an automated receipt control system (discussed in Section 5-V.B). For survey packages returned by the post office to Westat, a log was kept indicating establishment identification numbers and reason for return. This information was passed on to the interviewer, who then took responsibility for getting the survey materials to the respondent. Eleven percent of the packages were returned by the post office, and less than one percent were refused. However, field interviewers were able to contact nearly all of the establishments for which the package was returned.

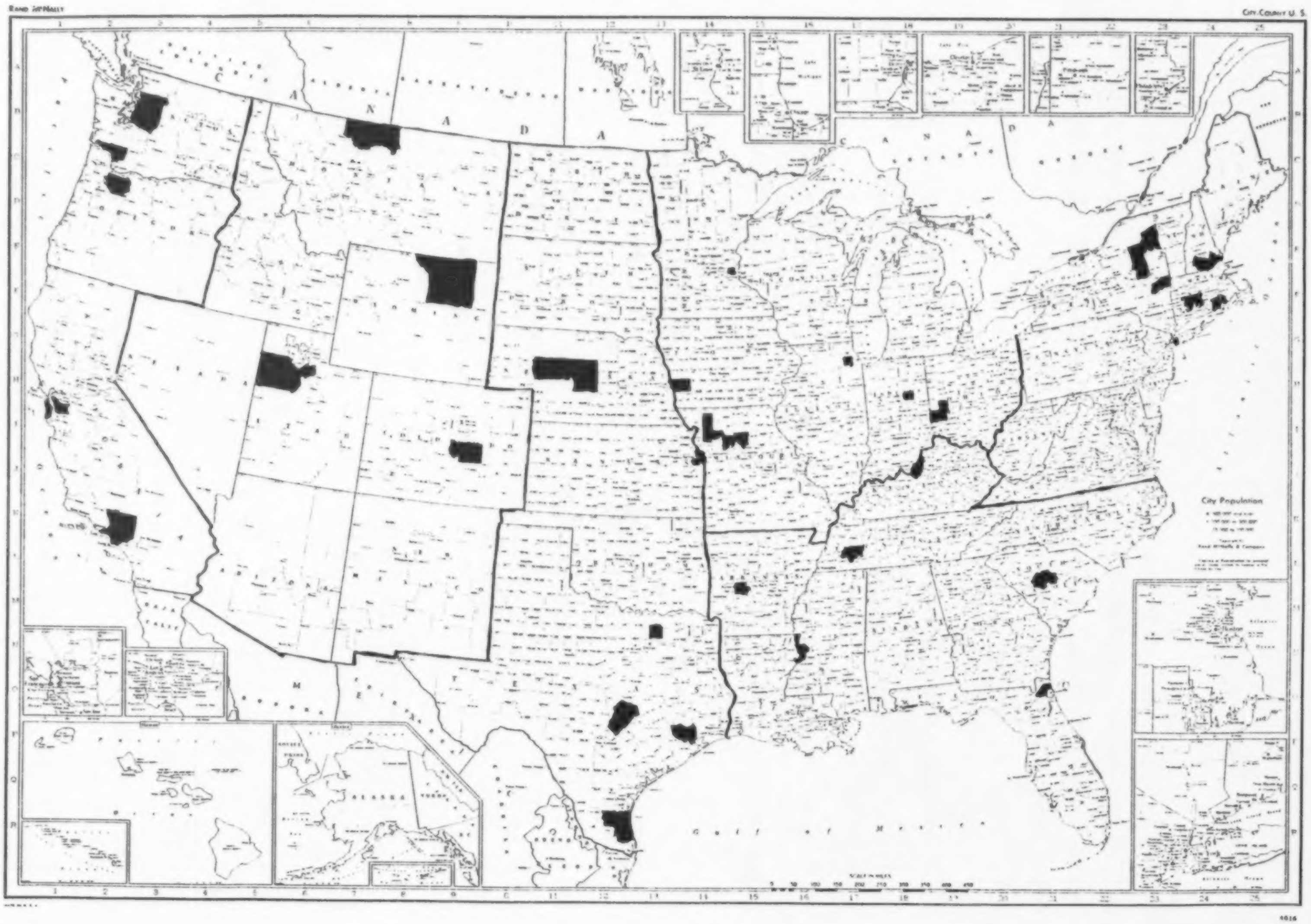
RAND McNALLY
CITY-COUNTY U.S.
CANADA
Gulf of Mexico
City Population
Rand McNally & Company

Figure B-1

A. UST Survey Package

Every establishment received the same package of survey materials, which were labeled with the establishment survey I.D. number, establishment name, and address. The package consisted of the following items, which are included as Exhibits in Appendix F:

- Open Letter to Owners and Managers of Underground Motor Fuel Storage Tanks -- An introductory letter that informed respondents of the need and purpose of the survey;
- "Certification Statement for Establishments without Tanks" -- A labeled form for the respondent to sign and return to Westat if there were no underground motor fuel storage tanks located at the establishment;
- "Reporting Responsibilities of Tank Owners and Operators" letter -- A one-page information sheet quoting the amended RCRA regulation that requires respondents to participate in the study;
- General Instruction Booklet -- A booklet describing procedures for completing the questionnaire and inventory forms. A "Request for Confidential Treatment of Business Information" form was included in the instruction booklet for the respondent to sign if necessary;
- Underground Storage Tank Survey Establishments Operator's Questionnaire -- One labeled copy was included to be reviewed by the respondent prior to the in-person interview;
- Inventory Sheet for Tanks with Metered Dispensing Pumps and Dispenser Meter Recording Sheet -- Six labeled copies were included in the package so that the respondent could begin to keep inventory prior to the interview;
- Manifolded Tank System Recording Sheet -- One labeled copy was included in the package; and
- Inventory Sheet for Tanks without Metered Disposal Pumps -- One labeled copy was included in the package.

A toll-free Westat "hot line" number was included in the introductory letter as well as in the General Instruction Booklet to provide survey assistance for the respondent.

IV. FIELD PROCEDURES

Fieldwork for the UST Survey began December 2, 1984. A staff of seven field interviewers was trained to collect data from the sampled establishments. Between one and three interviewers were assigned to cover a PSU depending on the numbers of establishments sampled per PSU. The interviewer's tasks in each PSU included eliminating ineligible establishments using field screening techniques, and scheduling and conducting on-site interviews. These procedures are discussed below in Section B-IV.A and B-IV.B. On the average, work in each PSU was completed in 15 days. The field phase of the UST survey concluded on June 29, 1985. However, data collection efforts through the mail and by telephone for incomplete cases continued until November 18, 1985.

A. Field Screening

An interviewer's assignment list for a PSU consisted of a call record folder for each establishment to be screened and interviewed. (See Appendix F for a copy of the UST call record folder). These lists included the farm and large establishments which could not be located through the Westat Telephone Research Center screening procedure. As a part of the initial appointment-making telephone call or visit, the interviewer determined whether the establishment did indeed have underground motor fuel storage tanks on site. In most cases, the interviewer was able to determine whether or not the establishment was eligible through an initial phone contact. Where phone contact was not possible, the interviewer traveled directly to the establishment site to speak with the respondent. Once eligibility for an establishment was determined, the interviewer then scheduled appointments for the in-person interview. Those establishments that sent the signed "Certification for Establishments without Tanks" prior to the beginning of fieldwork in a PSU were taken off the interviewer's assignment lists, and were not field-screened.

1. Statistics on Eligible Establishments

Table B-1 shows the number of establishments which were sampled, screened, and eligible for the UST Survey. Approximately three percent of all farms and 13 percent of all large establishments sampled were eligible for the survey (had underground motor fuel storage tanks). Almost 50 percent of all fuel-related establishments sampled were eligible. Reasons for ineligibility are discussed in Section 5-IV.A.2.

Table B-1. Number of sampled, contacted, and survey-eligible establishments, by sample stratum

	Farms	Large establishments	Fuel-related establishments	Total
Number sampled	598[1]	600	1,612[2]	2,810
Number contacted	596	596	1,608	2,800
Number of establishments contacted that have tanks ("eligibles")	20 (3.4%)	76 (12.8%)	800 (49.8%)	896

[1] 600 farms were sampled. Two farms were found to be duplicates in the telephone pre-screening.

[2] 1,618 fuel establishments were sampled. Six were found to be duplicates in the field screening.

2. Statistics on Ineligible Establishments

When a sampled establishment was determined to be ineligible for the survey the interviewer assigned an appropriate status code on the establishment's call record, and notified the Westat field director. Table B-2 contains the reasons for ineligibility and their frequency of occurrence by type of establishment. The majority of establishments were found to be ineligible because they had no tanks. Approximately 95 percent of all ineligible farms and large establishments fall under this category. Among the fuel-related establishments ineligible, 73 percent had no underground storage tanks. All establishments in Regions 1 through 5 found to have no underground motor fuel storage tanks through field screening procedures were instructed to sign and

Table B-2. Statistics on ineligible establishments

	Farms[1]	Large Establishments[1]	Fuel Establishments	Total
A. No. of establishments contacted	596	596	1,608	2,800
B. No. of ineligible establishments	576	520	808	1,904
C. Percent of establishments contacted that were ineligible	97%	87%	50%	68%
D. No. of establishments with no underground tanks	544 (94.4%)	495 (95.2%)	589 (72.9%)	1,628 (85.5%)
E. No. of establishments with abandoned tanks	13 (2.3%)	5 (1.0%)	92 (11.4%)	110 (5.8%)
F. No. of establishments out of business	11 (2.0%)	10 (1.9%)	75 (9.3%)	96 (5.0%)
G. No. of establishments out of PSU	6 (1.0%)	7 (1.3%)	41 (5.1%)	54 (2.8%)
H. No. of establishments out of scope of the survey	2 (.3%)	3 (.6%)	11 (1.3%)	16 (.9%)

[1] Statistics for farms and large establishments are a combination of the Telephone Research Center and field screening results.

return a statement certifying their establishment has no tanks (See Appendix F). Of the 745 establishments in the survey Regions 1-5 with no underground motor fuel storage tanks, 82 percent returned the "No Tank" form. For establishments in Region 6 with no underground tanks, the interviewer went directly to the site, observed there were no tanks, and picked up the signed form from the respondent. This was a quality control measure to check the accuracy of the certification.

Establishments which had abandoned tanks, were out of business, out of PSU, or out of the scope of the survey accounted for about 15 percent of the ineligible establishments.

It should be noted that if an establishment moved from the site sampled to a different location within the PSU, the establishment was considered eligible and the interviewer followed the establishment to the new location to conduct the interview. Also, if the owner of the establishment had sold the business, the current owner/operator was interviewed.

B. On-Site Procedures

Once at the establishment the interviewer had several types of data to collect. On-site procedures included an in-person interview using the EPA Underground Storage Tank Survey Questionnaire, a discussion on keeping inventory records, checking the accuracy of the fuel dispenser meters, making fill-pipe and drop-tube measurements, preparing or obtaining a site sketch map, and locating the establishment on topographical maps. The respondent was to gather the necessary data prior to the interview to prepare for the on-site visit as instructed in the survey package.

1. The Call Record Folder

All information and associated material gathered from the on-site visit of each establishment were kept in an individually labeled call record folder (Appendix F) for that establishment. The call record folder became the case jacket for the establishment and was preprinted with forms for address and name updating interview status reporting, contact and call recording, interview procedures guidelines, and an interviewer debriefing form. All materials, such as questionnaires and inventory information, collected at an establishment were labeled with the establishment identification number and filed in the establishment's call record folder.

For each PSU worked, the interviewer received a package of pre-labeled call record folders, each call record folder representing a sampled establishment. The label placed on the outside of each call record folder contained the establishment name, survey I.D. number, mailing address, tank location address, contact name, contact telephone number, and the county and state the establishment was located in. Below this label, in the Label Verification area, the interviewer noted any changes in the original information on the label. These changes were entered into the automated receipt control system described in Section B-V.B. Also on the front of the call record folder, the interviewer indicated the completion status of each on-site procedure. Printed inside each folder was a script the interviewer followed which led him/her through the interview. Also printed inside the folder were a set of debriefing questions which asked how willing and prepared the respondent was for the on-site visit. A record of all calls to the establishment or the respondent was kept on the back of the folder. Each call record folder had additional survey identification labels stapled inside to be used for labeling any materials or records received during the interview.

2. The Questionnaire

The questionnaire body is divided into eight sections, with each section focusing on a particular topic or concern.

o Section A: Establishment Descriptive Information

Section A has two purposes. The first purpose of the section was to describe the type of establishment that was being interviewed. (Question A1 was an industrial classification, for example.) The second purpose of the section was to find and "screen out" any remaining "out-of-scope" cases. Question A1 had a screening-out route for bulk fuel plants and private residences, for example. (Private residences were completely out of scope. Bulk fuel plants were only in scope if they had motor fuel storage that was non-bulk, for use directly by motor vehicles. Private residences and bulk fuel plants were asked to call the Westat home office for instructions on how to proceed.)

Question A6 was another screening question. Naturally, given the nature of the survey, establishments that did not have underground motor fuel storage tanks were not to be interviewed. (Also, in Question A6 any underground storage tanks that were permanently out of service or that were used only to store non-motor fuels such as chemicals of heating oil were excluded.) Question A11 was used as a lead-in to the Tank Description Sheet (which is described below) and also asked the respondent to provide or draw a map of the establishment. The primary purpose of the map was to help the field interviewer establish the location and linkages between the tanks, pumps, and meters at the establishment. The tank testing crews also used the map to help identify the tanks to be tested, as well as to correctly number the tanks on their data forms.

o The Tank Description Sheet

The Tank Description Sheet is a two-page sheet containing specific questions about each tank at the establishment. A total of 44 items about each tank include questions on the amount of fuel held in the tank, the materials of construction, year of installation, safety features, leak history, etc.

Tank Description Sheet information is used in conjunction with tank test results in order to learn more about the factors and features of tanks that are associated with leaking. The information from the Tank Description Sheets was also used by the tank testing crews. For these reasons it was of great importance that the tank identification number of the Tank Description Sheet and the tank identification number on the map and the inventory were all the same.

- **Section B: Operating Practices**

The particular focus of Section B is on the establishment's typical inventory record-keeping and inventory management practices. The interest here is in the establishment-kept records, in factors associated with the accuracy of those records, and in the kinds of records that were kept.

- **Section C: Operating History**

This section contains questions that fill in the establishment's past tank history. The Tank Description Sheets provide basic historical information about the tanks currently in use. In Section C information is obtained on tanks that have been replaced, removed without being replaced, or abandoned in place, and in the number, the date and the reason for each of these three actions.

- **Section D: Permits and Licenses**

Section D comprises two questions about permits and licenses a respondent has to install and operate his tank.

- **Section E: Installation**

Section E is a short series of questions about the methods by which the tanks were installed at the establishment.

- Section F: Protection

Section F asks about the types of leak-protection, corrosion-protection, and leak-detection devices that have been installed at the establishment, and the kinds of operating and maintenance practices for the devices.

- Section G: Information Needs and Availability

Section G focuses on the kinds of information and training relating to tank operating and monitoring that were available to the respondent. Also included were questions which asked the respondent about types of liability insurance held by the establishment to cover sudden and non-sudden spills (and leaks) of motor fuel.

Interview responses varied depending on how knowledgeable the respondent was and how willing he/she was to participate. Often, it was necessary for the interviewer to speak with more than one respondent to get enough information to complete the questionnaire. In some instances, the interviewer was unable to get any information from the on-site respondents at all. Operators of establishments owned by multi-establishment corporate structures occasionally referred the questionnaire to their home office, which was always off-site and generally outside the PSU where the interviewer was located. In these cases, followup calls from Westat were made to obtain the completed questionnaire. Interview response rates are discussed in Section B-V.F.

3. Reviewing the Inventory Sheets

After completing the interview with the respondent, the next step for the interviewer was to review the inventory forms. Included in the survey package the respondent received were four kinds of motor fuel inventory sheets, a schematic diagram of the seven most common tank and dispenser hookup systems (in the General Instruction Booklet), and an Inventory Recording Table (in the General Instruction Booklet) to help him choose the correct inventory sheets to use for his establishment. The respondent should have started keeping inventory on these forms prior to the interview. Because of the complexity of the data being gathered, the interviewer was instructed to always review the inventory sheets with the person responsible for keeping them. This was not always the same respondent who answered the questionnaire. Depending on the size and type of establishments, several people were sometimes involved in keeping the inventory records. It was the interviewer's job to make sure the respondent understood the inventory process and was filling the forms out correctly. If the respondent chose to provide 30 days of previously collected inventory, the interviewer reviewed the data carefully and made sure all the necessary information was provided (or that the respondent knew what information was necessary if previously collected inventory was to be mailed in from another location, for example, a home office where all records were kept).

Before reviewing the inventory forms, the interviewer had to verify that the tanks and meters were numbered the same on the map drawn by the respondent in the questionnaire, in the Tank Description Sheets, and on all inventory forms. It was very important to make sure these numbers corresponded in order to link data from inventory forms and tank tests to the questionnaire data. The interviewer used the Tank to Dispenser Meter Fuel Line Connections Sheet (Appendix F) to cross-check the linkage system. This was done at the actual physical location of the tanks, where tank and meter numbers were positively identified.

After the inventory review, respondents were told that someone would be contacting them within the next two weeks to check on the status of the inventory forms. They were given a toll free 800 number to call if they had any problems or questions with the inventory recording procedures. The interviewer also gave the respondent a postage-paid pre-addressed envelope for returning the completed forms. Inventory response rates are discussed in Section B-II.F.

4. Checking Meter Accuracy

Once all tank and meter numbers were verified and inventory sheets reviewed, the interviewer checked the accuracy of all dispenser meters using a five-gallon certified meter calibration can. For each meter tested, a calibration (adjustment) ratio was recorded on the appropriate inventory form. Using this ratio, the inventory records were adjusted by computer to account for the meter error.

The accuracy testing procedure was the same procedure used by agencies that certify meter accuracy. The interviewer first pumped approximately one gallon of fuel into the can to wet the inside. This reduced the surface tension inside the can and allowed for a more accurate measurement. After wetting the can, the fuel was returned back into the appropriate tank and the meter reset to the zero (0.0) reading. Next, the interviewer pumped five gallons of fuel into the test can and read the level of fuel according to the measuring gauge on the front of the can. The can was used to measure error in liters or gallons. A "calibration ratio," which equaled the gauge reading divided by the amount pumped into the can, was recorded for each meter tested. The ratio was recorded in "cubic inches" (in^3) if the fuel was dispensed in gallons or in "milliliters" (ml) if the fuel was dispensed in liters. A negative (-) or positive (+) sign was always recorded with the ratio, to indicate whether the pump was dispensing less or more than the amount indicated by the meter.

After recording the calibration ratio, the interviewer returned the fuel to the tank from which it came. The calibration of all meters associated with the same tank were checked before going to the next. If the respondent had already started keeping inventory records, the amount of fuel returned to the tank was recorded as a "delivery" on the inventory sheet, in order to balance with the meter readings in the inventory records.

5. Measuring the Fill Pipe/Drop Tube

The next procedure after checking meter accuracy was to measure the diameter of the tank fill pipe. The interviewer also had to determine whether or not a drop tube was present inside the fill pipe and, if present, whether the drop tube was permanent or removable. This was done for each underground storage tank and the data recorded on the Site Observations Recording Sheet (Appendix F). This information was collected by the interviewer to help prepare the MRI crew for tank tightness testing. Certain factors, such as the size of the fill pipe or the presence of a permanent drop tube hindered or prevented a tank test. Knowing this beforehand, the crew was prepared to solve the problem once on site for the test.

6. Map Reading

The interviewer was provided with topographical maps of each PSU, which were included in the package with the call record folders for establishments to be interviewed. These are U.S. Geological Survey maps and are graphic representations of selected man-made and natural features of the earth's surface plotted to definite scales. Such maps record physical characteristics of the terrain as determined by precise engineering surveys and assessments. Using a standard symbol guide to help read the maps, the interviewer located the tanks on the map, circled the location, and identified it using the survey I.D. number for that establishment. The interviewer returned the unused maps to EPA. The maps with tanks located on them were returned to Westat, where they were reviewed to make sure all establishments for that PSU were mapped, copied, then sent to EPA. Using the precise longitude and latitude of the tanks from the map, soil characteristics and other physical characteristics of the site could be matched to the tanks specific for that location. There were fewer than 20 sites for which USGS topographic maps could not be obtained, and these were covered to the extent possible by local street or road maps. The data obtained through the map linkage are discussed in Appendix H.

C. Interviewer Evaluation

Immediately after leaving the site, the interviewer completed the debriefing questions printed inside the call record. These eight questions were used to evaluate the overall character of the interview and the cooperation and knowledge of the respondents. Table B-3 shows the debriefing statistics for the 890 establishments surveyed.

Table B-3. Debriefing statistics

	Percent
Percent of respondents who had questionnaire completed prior to interview	28%
Percent of respondents who had inventory sheets started	12%
Percent of respondents who had problems or errors in completed parts of inventory	31%
Percent of respondents who understood inventory process	98%
Percent of respondents who understood most/all questions in questionnaire	99%
Percent of respondents who were cooperative	94%
Percent of respondents who were hostile	3%
Percent of respondents who were guessing a lot in answering interviewer's questions	4%
Percent of establishments where it was necessary to talk to more than one person to obtain all required information	29%

Less than one-third of the respondents had prepared for the on-site interview by completing the questionnaire prior to the interviewer's arrival on site. Only 12 percent had started keeping inventory records prior to the interview. Of those respondents who had started keeping inventory records, the interviewers found that 31 percent had errors in the completed parts of the inventory. Almost 100 percent of the respondents understood the inventory process and the questions in the questionnaire. In approximately 30 percent of all cases it was necessary to talk to more than one respondent to obtain all required information. Even though most respondents were unprepared for the survey, 94 percent were willing to cooperate.

After completing the debriefing questions, the interviewer made necessary name and address changes to the label in the Label Verification section of the call record. If it was necessary to talk to more than one respondent, a contact name and phone number for each respondent interviewed was written on the front of the call record. The interviewer then assigned a questionnaire completion status for the case and circled the appropriate completion status codes for the inventory record keeping, the meter accuracy test, the site mapping, the debriefing, and the confidentiality request form. After checking to make sure that all materials in the call record were properly labeled and editing the questionnaire for completeness, the interviewer returned the completed case to Westat, where it was reviewed and entered into the receipt control system (discussed in Section B-V).

D. Refusals

Each sampled establishment received a survey package containing a copy of the Resource Conservation and Recovery Act (RCRA) amendments to Section 9005(a) stating that the responsibility of the tank owners and/or operators to furnish information for the UST Survey. Nevertheless, a small number of respondents still refused to participate. When an interviewer encountered a refusal to participate either over the phone or in person, he/she told the respondent that the EPA legal office would be informed of the refusal. The interviewer then contacted the Westat field director immediately. The field director notified EPA's Office of Enforcement and Compliance Monitoring of the refusal by phone and by letter. In most cases, the respondent agreed to participate after a phone call from an EPA attorney. In other cases, a warning letter from the Waste Enforcement Division was sent to the respondent when a phone call did not result in cooperation.

Some respondents refused to participate in any part of the interview, while others only refused to keep the inventory records. The number of interview and inventory final refusals is shown in Table B-4, lines F and J respectively. Overall, less than one percent of respondents refused to complete the interview and less than two percent refused to complete the inventory recordkeeping.

When a respondent who had initially refused the interview decided to participate (either as a result of a phone call or enforcement letter) the Westat field director was notified. If the field interviewer was still on site in that PSU, an interview was set up with the respondent. If the interviewer had already left the PSU, the person assigned to "clean-up" (see Section B-IV.E) these special cases made the appointment and completed the interview.

E. Interview "Clean-Up"

It was necessary to use a "clean-up" interviewer who followed behind the field teams, to handle special circumstances when all on-site procedures could not be completed during the

Table B-4. Field interviewing and inventory status statistics

	Farms	Large Establishments	Fuel Establishments	Total
A. Number sampled	598[1]	600	1,612[2]	2,810
B. Number contacted	596	596	1,608	2,800
C. Number of establishments contacted that have tanks ("eligibles")	20	76	800	896
D. Number of interview responses	19	76	795	890
E. Response Rate (percent of eligible respondents who completed interview	95%	100%	99.4%	99.3%
F. Number of interview refusals	1	0	5	6
G. Refusal rate (percent of eligible respondents who refused interview)	5%	0%	0.6%	0.7%
H. Number of inventory responses (includes both complete and partial complete)	7	60	630	697
I. Response rate (percent of eligible respondents who returned inventory)	35%	79%	78.8%	77.8%
J. Number of inventory refusals	6	1	8	15
K. Refusal rate (percent of eligible respondents who refused to record inventory)	30%	1.3%	1%	1.7%
L. Number of delinquent inventory responses	4	9	131	144
M. Number of establishments for which inventory measurements are impossible	3	6	31	40

---

[1] 600 farms were sampled. Two farms were found to be duplicates in the telephone pre-screening.

[2] 1,618 fuel establishments were sampled. Six were found to be duplicates in the field screening.

time the interview team was working in a particular PSU. Some of these special circumstances included the following:

- The respondent most knowledgeable of the underground storage tanks was unavailable during the time the original interviewer was in the PSU.
- The respondent had refused to participate and decided to participate after the original interviewer left the PSU.
- The business was closed due to seasonal operation when interviews were being conducted in the PSU.
- The establishment was remodeling its underground storage tank systems and could not provide all necessary data at the time interviews were being conducted.
- A calibration check could not be done due to adverse weather conditions or seasonal operation of the establishment.
- An establishment could not be located by the original interviewer.

Work done by the "clean-up" interviewer accounted for five percent of all completed interviews.

F. Field Interview Data Collection Statistics

Table B-4 contains data collection statistics for the field interview portion of the survey. It covers statistics on interview and inventory response and refusal rates.

1. Interview Response Rate

The interview response rate for this mandatory survey is nearly 100 percent overall, as well as for each sample segment. Out of 2,800 establishments contacted, 896 had underground motor fuel storage tanks, and were therefore eligible for the survey. Of those, 890 or 99.3 percent completed interviews. The highest response rate among the sample segments was among the large establishments, where 100 percent of the eligible establishments provided interview data.

2. Inventory Response Rate

Nearly 78 percent of the eligible establishments have furnished complete or partial inventory data. Even this low response rate was achieved only after extensive edit and followup efforts by Westat's survey staff. Sixteen percent of the eligible establishments have not yet provided inventory records. It was impossible for 4.5 percent of the eligible establishments to keep inventory records. These reasons are discussed below in Section B-IV.F.3.

3. Problems Preventing Inventory Record Keeping

Of the 896 eligible establishments, 40 were unable to provide inventory records for any of their tanks using the designated record keeping procedures. The reasons are listed below.

- No conversion chart -- Twelve establishments were unable to obtain conversion charts needed to convert inches to gallons for their tanks because they did not know the dimensions of the tanks or the company which installed them.
- Bent fill pipes -- Nine establishments were unable to stick their tanks because the fill pipes were installed with a bend to prevent pilferage.
- Facility closed -- Seven establishments have closed down since the time of the interview.
- Tanks abandoned/removed -- Five establishments have either removed or abandoned their tanks since the time of the interview.
- No inactive period -- Inventory analysis procedures for tanks without meters to record the total product dispensed consists of an analysis of volume measurement changes for inactive periods. Four establishments, which have tanks without meters, dispense fuel 24 hours a day, so there is no inactive period to analyze.
- No way to record deliveries -- Two establishments pumped fuel at irregular intervals from an above-ground tank into the underground storage tanks with no means of measuring the amount pumped into the tanks.
- No key to tank -- The locked tank of one establishment was inaccessible due to delay caused by probation of the estate of the tank operator, who died with the only key in his possession.

V. DATA PREPARATION

Data preparation for the UST Survey began with a development phase involving questionnaire layout and code manual design. Inventory recording forms were developed by EPA. The coding format, however, was designed by Westat. Operational phases included document handling (including receipt control), coding/editing, data entry, and machine editing. Location coding from the topographic maps is discussed in Appendix H.

A. Questionnaire and Code Manual Design

The questionnaire layout was designed for ease of data preparation/data processing, as well as for ease of respondent understanding and recording. Many items were designed as "precoded" questions, that asked the respondent to answer by circling a code to indicate his/her response. This eliminated the need for a coder to translate check-marks or other non-code symbols into coded answers. Computer field positions were printed in the questionnaire for most data items. These field positions were useful as reference locations for coders, machine editors, and data entry staff.

A detailed code specification manual using an automated code book formatting program for the UST Survey Questionnaire was developed. This manual described the data to be encoded from the questionnaire, item by item. Figure B-2 lists the item characteristics by which each data item was described in the code manual. Figure B-3 is an example data item description from the Underground Storage Tank Survey Establishment Operators Questionnaire.

Item characteristics described in code manuals

a. Field position and record number

b. Item name (the name by which the item was called in all computer programs and other documentation)

c. Quotation of the item from the questionnaire

d. List of all code values and their definitions

e. List of reasons for legitimate item nonresponse (the "inapplicable" definition)

f. List of all missing value codes

g. Flags indicating logical relationships between the item and subsequent items.

Figure B-2. Item characteristics described in code manuals

```
F2A         020-022       FREQUENCY_OF_INSPECTION

                          ++                = INAPPLICABLE, CODED 2, 8, OR 9 IN F1A,
                                              COL 016, REC 09; OR CODED 1, 8 OR 9 IN
                                              BOXF2, COL 19, REC 09
                          001-365           = FREQUENCY OF INSPECTION
                        * 998               = DON'T KNOW
                        * 999               = NOT ASCERTAINED

                        * SKIP F2UC, COL 023-024, REC 09
```

Figure B-3. Code manual data item description

B. Inventory Data Editing

Inventory forms were designed to include "worksheets" for respondents to record individual meter and manifolded tank readings, and then to record the sums of the individual readings. Both the individual readings and the summary readings were edited and key punched. The raw data collected from the inventory recording process was entered or key punched (Section B-V.D) directly from the edited inventory forms. A code manual and editing instructions detailing the layout and the valid code ranges for the inventory forms was prepared to assist the editors and the data entry operators.

C. Receipt Control

All returns were tracked by Westat's automated receipt control system. Each day, documents received, including certified mail cards and "No Tank" Certification statements, were keyed into the system. All documents from an establishment were linked by a survey identification number specific to that establishment (discussed in Section B-V.B.1). Using this I.D. system, returns were tracked by type of document, and reports on the survey status and on an individual establishment status were produced.

For each document received, the date of receipt, a status code and "batch" number (Section B-V.B.2) were entered into the receipt control system using the procedure specific for that document. In addition, any name or address changes from the call record were also entered upon receipt of a questionnaire from the field.

1. Survey Identification Number

The survey I.D. number is a ten-digit number which shows the sampling frame from which the establishment was selected, the PSU in which it is located, and a sequential number. The survey I.D. uniquely identifies the establishment within the survey and links all documents and data records for the establishment.

2. Questionnaire and Inventory "Batching"

Questionnaires and inventory forms were "batched" into groups of 10 documents for coding, editing, and filing purposes. Each batch was given a number, which was written at the top of the Batch Control Sheet (Figure B-4), as well as on the questionnaire or inventory form. Questionnaires and inventories were batched separately. Listed on the Batch Control Sheet were the survey I.D. numbers of all the questionnaires (or inventories) and their statuses for that specific batch. Questionnaire and inventories remained in their batches until they were coded and sent to data entry. If they were removed from the batch for any reason, the date, person taking the document, and reason were noted on the front of the Batch Control Sheet. A copy of each Batch Control Sheet was kept in a log for quality control purposes for both questionnaire and inventory batches.

BATCH CONTROL SHEET

BATCH |__|__|__|__|

	ID LABEL	STATUS	CHECK OUT TO/ON	DATE RETURNED	VERIFIED BY
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

CODER: ______________

DATE: ______________

VERIFIER: ______________

DATE: __________ % VERIFIED: ______

Figure B-4

D. Coding/Editing

A staff of six coder-editors was trained to code the questionnaire and inventory. The initial training session covered procedural matters as well as specific coding of the UST Survey Operators Questionnaire and the four types of inventory recording forms. It included an item-by-item discussion of the coding of the documents, practice coding examples, and group review of the coding of practice examples. Training materials included code manuals, practice inventory and questionnaire examples, and a marked-up version of the questionnaire that linked the questionnaire to the code manual and the general coding instructions.

Coders were trained to edit questionnaire responses and inventory records for consistency and completeness as they were coding them. Coders flagged any problems they discovered during coding, and referred the problem documents to the coding supervisors. Some problems required the development of new codes -- such as when different units of measure than those specified in the questionnaire were specified for quantity questions. Other problems required that the respondent be called to verify a response or provide missing information (a process called "data retrieval"). In some instances, decisions could be made based on the evidence available, by the Project Officer or by other EPA staff. Decisions, both general and case-specific, were recorded in a Decision Log for future reference.

All coding was 100 percent sight verified by a senior coder or the coding supervisor prior to being sent for data entry.

E. Data Entry

Questionnaire and inventory data were entered ("key punched") by highly trained data entry operators, using a key-to-tape entry system. This key-to-tape system is computer-driven and provides a formatted entry keying program that minimizes many types of data entry errors. All data entry was 100 percent key verified by a different operator from the entry operator.

The questionnaire booklets and inventory records were sent to data entry in "key batches." Lists of the survey I.D. numbers associated with each key batch of inventory records were made and put into a Key Batch Control Log. All questionnaires sent to data entry were checked off against a list of completed interviews, which was generated by the receipt control system. This enabled the coders to make sure that all questionnaires were keyed.

F. Machine Editing

Machine editing is a means of data quality control that uses a computer program to test item ranges, skip patterns, and logical consistencies in a data file. Such a machine edit program was prepared for the questionnaire and for the inventory forms.

Machine editors were selected from among the trained coders available from the coding staff. The training consisted of procedural instructions, and a walk-through using an example edit problem.

The machine edit programs provided a list of test errors for each edited case, as well as a listing of each case in error. Each of the errors was checked, and often the hard copy of the case was reviewed. Updates to the data files were written on update sheets, key-entered and run against the data file to produce a new master file. Then the edit cycle was rerun to make sure that the update corrections had been made correctly. Because of the complexity of some of the data files (particularly inventory data files), it was necessary to rerun edit cycles several times: updates to some fields tended to unexpectedly impact consistencies with other fields.

After the final machine edit cycles, frequency distributions for all items of the data files were reviewed by supervisors to spot problems not captured by the machine edit programs.

VI. DATA RETRIEVAL

Data retrieval is the term used to refer to recontacting respondents for the purpose of verifying or clarifying responses to completed questionnaires for interviews. For this study, it was necessary to recontact respondents for problems found in the inventory records as well as questionnaires. These questionnaire and inventory data retrieval procedures are discussed separately below in Section B-VI.F.1 and B-VI.F.2. Part of the coding staff was trained for the data retrieval process.

A. Questionnaire Data Retrieval

Recontact of respondents for questionnaire problems generally took the form of a telephone call, though occasionally it was necessary to mail a list of questions to a respondent. Approximately 60 percent of all respondents were recontacted for questionnaire data retrieval.

B. Inventory Data Retrieval

Because of the complexity of the inventory record-keeping procedure, each respondent received a "prompt" call by Westat approximately two weeks after the field interviewer left the site. The purpose of the call, which was made by a staff member trained for inventory data retrieval, was to inquire about he status of the inventory and when the records would be completed. The prompt caller also assisted the respondent with any questions or problems that may have occurred about keeping the inventory.

A large proportion of the inventory records received from the respondents contained errors or inconsistencies ranging from minor to major. When these problems were spotted by coder-editors or coder-verifiers, the inventory form was flagged for inventory data retrieval. The inventory data retrieval process began with a phone call to the respondent with a discussion of the problem. Some problems were resolved on the telephone. Often, an explanatory letter and copies of the returned inventory with problem areas marked were sent to the respondent. The respondent then sent corrected inventory records back. It was sometimes necessary to send multiple letters explaining the problem before usable data was returned. Of the 697 inventory responses received to date, approximately 85 percent needed data retrieval, four percent of which needed multiple data retrieval efforts. At the writing of this report, there are still establishments which have not yet responded to the data retrieval efforts. They account for 25 percent of all cases needing data retrieval.

C. Followup of Inventory Nonrespondents

After multiple prompt calls were made to inventory nonrespondents, EPA sent a formal warning letter (Figure B-5) and Status Report form (Figure B-6) to respondents who were delinquent in returning inventory records. Of the 300 letters sent, 25 percent did not respond and two percent refused.

As a result of all data retrieval efforts made by Westat and EPA, 78 percent of all establishments have sent in inventory records, but approximately 50 percent of all inventory records received are complete enough for inventory reconciliation analysis. Of the 896 eligible respondents, 16 percent have not yet returned inventory records.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

OFFICE OF
PESTICIDES AND TOXIC SUBSTANCES

AUG 16 1985

Dear

The Environmental Protection Agency (EPA) has been informed by Westat, the Agency's contractor for the National Survey of Underground Motor Fuel Storage Tanks, that as of July 31, 1985 the 30 days of motor fuel inventory data you are required to provide EPA had not been received.

As was explained in the survey instructions mailed earlier, Congress passed and President Reagan signed into law in 1984, amendments to the Resource Conservation and Recovery Act (42 U.S.C., Sec. 6901) that require EPA to conduct this study. This law also requires that you, as an owner or operator of an underground motor fuel storage tank, provide EPA with the information requested in this survey.

I wish to stress that the evaluation of inventory data is an essential part of this National study, and EPA is requiring this information from all establishments selected for the survey. Failure to comply with this requirement may result in an enforcement action.

Enclosed is a form for reporting the status of your 30-day inventory data collection. We ask that you complete and return the form within 24 hours of receipt to verify that you are complying with this requirement. Simply check and complete the correct inventory status block, sign and date the form, and mail it in the enclosed self-return envelope.

Thank you for your cooperation.

Sincerely,

Martin P. Halper, Director
Exposure Evaluation Division

Figure B-5

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

MOTOR FUEL INVENTORY STATUS REPORT

Please complete this form and mail in self-return envelope wihtin 24 hours.

☐ I have completed and mailed my 30-day inventory data to Westat.

☐ I am still collecting my 30-day inventory data and will mail it to Westat by ______.
(date)

☐ I have not yet begun my 30-day inventory data collection but will do so immediately and mail it to Westat by ______.
(date)

☐ I need further instructions to complete and submit my 30-day inventory data collection.*

☐ Other situation (please describe). ______________________

____

____

____

____

____
(Signature)

____
(Date)

---

*Phone toll free (800) 638-8985

Figure B-6

APPENDIX C

DEVELOPMENT OF A TANK TEST METHOD

This appendix is a summary of the report, "Development of a Tank Test Method for a National Survey of Underground Storage Tanks." The work was conducted under EPA Contract No. 68-02-3938, Work Assignment No. 25.[1]

The appendix first summarizes the search for a suitable tightness testing method and the reasons for the final selection. Then the field procedures developed in the pilot test are described. A more detailed description of the field tightness test plan may be found in the test and analysis plan.[2]

I. SELECTING A METHOD

In preparation for the field tightness testing, MRI first searched for a suitable test method. Their objectives were to evaluate potential test methods to be used for the national survey, to conduct a pilot survey using the test method selected, and to develop a test plan for the national survey. The research was conducted in five stages. The first stage consisted of a review of current methodology for detecting leaks in underground tanks. Second, field observations were made of several methods in use. Third, of the several methods observed, five were selected to be evaluated by conducting tests of these methods on a single tank system at a closed service station. Three of these five methods were selected for further evaluation in the fourth stage by testing tank systems at four military installations and at an operating service station. In the final stage, the method chosen for use in the national survey program was tested in a pilot study of 17 tank systems.

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[1] "Development of a Tank Test Method for a National Survey of Underground Storage Tanks," H.K. Wilcox, J.D. Flora, C.L. Haile, M.J. Gabriel, and J.W. Maresca, April 1986.

[2] "Test and Analysis Plan for the Tank Testing Program of the National Survey of Underground Storage Tanks," H.K. Wilcox, J.W. Maresca, Jr., J.D. Flora, C.L. Haile, June 10, 1985.

II. GENERAL METHOD SELECTION CRITERIA

The main criteria used to select a method for the national program were:

1. Quantitative measurements were desired. However, this did not preclude consideration of other approaches.
2. A detection level of 0.05 gal/h as established by the National Fire Protection Association, Inc., was taken as the target detection limit.
3. Minimal disruption to the station operation was considered to be important.
4. The method and equipment had to be rugged for use on the national survey.
5. The test should be applicable in a wide variety of tank system configurations.
6. The method should allow a reliable assessment of accuracy, precision, and sensitivity.
7. Costs for testing and data analysis had to be within the available budget.
8. Sufficient equipment and manpower to conduct the national survey were required.

The scope of the method selection research and pilot study did not permit exhaustive method evaluation of all available test methods in order to select a procedure with optimum characteristics for all criteria. Hence, some compromise was necessary to proceed expeditiously with the survey.

III. PRELIMINARY REVIEW AND TESTING

The methods reviewed in the first stage are shown in Table 1. Those for which further evaluations were conducted are also indicated. The methods were classified into groups according to their measurement characteristics.

Five methods were selected for further testing at a closed service station in Kansas City. Brief descriptions of each are provided below. A more complete review of tank testing methods can be found in EPA's report.[3]

- The ARCO method utilizes a photo optical sensor to monitor the level of a partially filled tank. If the test conditions are set up properly, the device is self compensating for temperature changes. Only the portion of the tank containing the product is tested.
- The Certi-Tec method uses pressure transducers which are located just below the surface of the liquid to measure level changes. Seven thermistors are used to measure temperature at various levels in the tank during testing. The tank is overfilled during the test by adding an extension to the fill pipe. Both the tank and lines are tested at the same time.

---

[3] "Underground Tank Leak Detection Methods: A State of the Art Review," EPA/600/2-86/001, January 1986.

Table 1. Leak Detection Methods Reviewed

Detection method	Literature review	Field site visits	Preliminary testing	Development study	Pilot study
Volumetric					
ARCO tank test	X	X	X	X	
Certi-Tec test	X	X	X		
Ethyl Tank Sentry	X				
Ezy-Chek	X				
Heath Petro-Tite tank and line testing system	X	X	X	X	X
Hydrostatic (standpipe) testing	X				
Lasar interferometry	X				
Leak Lokator test	X	X	X	X	
Mooney tank leak detector	X				
Pald-2 leak detector	X				
Pneumatic testing (air test method)	X				
Non volumetric					
Dye method	X				
Vacutect method	X				
Helium leak detection method	X	X	X		
Tracer Research	X				
Inventory monitoring					
Manual methods	X				
Automated	X	X			
External monitoring					
Pollulert	X				
Remote infrared sensing	X				
Ground water and soil core samples	X	X		X	
Underground radar	X	X			

- Leak Lokator uses a buoyancy probe to monitor level with a single thermistor located at the midpoint of the tank. The method can be used to test a partially filled tank (with lower sensitivity) or an overfilled tank. Either the tank or the tank and lines can be tested.

- The Petro-Tite method monitors level visually in an extended fill pipe. The product level is returned to the reference level at 15 minute intervals during the test. The product is stirred continuously during the test to achieve a uniform temperature. Temperature is monitored with a single thermistor located at the inlet to the pump near the top of the tank. The tank and lines are all tested at the same time.

- The Varian helium leak detection method, a nonvolumetric method, is based on the detection of helium outside a tank which has been slightly pressurized with helium. The tank should be empty during the test if the entire tank is to be tested. It is also helpful to drill a number of small holes in the surface above the tank to assist in the location of the leak. Pressure can be monitored simultaneously to provide a quantitative estimate of the leak rate. The lines are also tested at the same time.

A. Experimental Procedures

Each method was tested over a 2- to 3-day period. A leak simulation system was designed and fabricated by MRI and used to draw product from the tank at a known rate. The precision of the leak simulator was at least an order of magnitude better than that of the test methods. In testing the tank, the objective of each test group was to estimate different simulated leak rates. The leak rates measured by each method were compared with the rates used in the simulation.

The data from the quantitative tank tests were analyzed to determine the precision and accuracy of the tests. For these analyses the accuracy of the test (or bias) was estimated by the mean of the (signed) differences between the leak rate reported and the leak rate simulated. A paired t-test was used to test the hypothesis that the method was unbiased; that is, that the mean signed difference was 0. A linear regression of the reported leak rate on the simulated leak rate was calculated. An ideal regression equation in a tight tank would be y = 0 + 1.0x. The scatter of the data about the regression line (correlation coefficient, R) was used as an estimate of the precision of the method. The bias and precision were combined to obtain an estimate of the root mean squared (RMS) error.

B. Results

A summary of the statistical analysis for the quantitative methods as a group is presented in Table 2.

1. ARCO Underground

The ARCO method was used for 15 different simulated leak rates, including one zero rate. An average difference of 0.01 gal/h was observed between the rates reported by ARCO and those calculated by MRI. This estimated bias in the results was not significantly different from 0 (t = 0.21, 14 degrees of freedom). The intercept did not differ significantly from 0 and the slope did not differ significantly from 1. The R for the regression was 94.3 percent, indicating that most of the variability of the data was explained by the regression. The RMS error estimated for the method under the conditions of the Kansas City test was 0.05 gal/h. The tests averaged just under an hour (55.7 min) in length. In order to reduce the variability estimated with the method, either repeated determinations or a longer test time would be needed.

Table 2. Summary of Statistical Analyses of Quantitative Methods Tested at Kansas City Site

Method	n[a]	Bias	Intercept	Slope	Standard error	RMS	R^2
ARCO	15	0.01	0.005	0.95	0.049	0.050	94.3%
Certi-Tec	12	-0.25	-0.30	0.71	0.166	0.302	38.9%
Leak Lokator	22	-0.01	-0.01	0.94	0.020	0.021	98.9%
Petro-Tite	18	0.05	0.06	1.05	0.101	0.113	75.9%

[a] n = number of simulated leaks.

2. Certi-Tec Method

The Certi-Tec method was used for 12 simulated leak rates, of which two were set at 0 and so represented the normal condition of a tank test. The leak rates reported by the Certi-Tec method took slightly over an hour (average 64.3 min) for each rate. The estimated bias in the results (difference between the reported rate and the simulated leak rate) averaged -0.25 gal/h. This bias was quite large and was significantly different from 0 ($t = -5.23$, 11 degrees of freedom). The intercept differs from 0 at the 5 percent significance level and the slope differs from 1 at the 5 percent significance level as well. The standard error of the regression was 0.167 gal/h. The R of the regression was only 38.9 percent, indicating that slightly less than 40 percent of the variability in the reported leak rates was explained by the simulated leak rates used in the test.

Thus this method, as implemented during this test, appears to have substantial bias and relatively low precision. Even though taking several repeated determinations of the leak rates and averaging them would reduce the random error, the bias would remain a problem.

3. Leak Lokator Method

The Leak Lokator method was used on 22 tests simulating leak rates. Of these, three were zero simulated leak rates and so represented tests of the tank without any simulated leak. Three simulated leaks into the tank were also used. Using the method, the average reported leak rate was 10.8 min.

The bias in the determinations was estimated to be -0.005 gal/h, which was not significantly different from 0 (t = -0.23, 21 degrees of freedom). Although the estimated slope and intercept agree closely with the ideal, both differed from the ideal values significantly at the 5 percent level although not at the 2 percent level.

These data showed a very small scatter about the regression line, resulting in small estimated values for the standard error of the slope, intercept, and regression. These small standard errors led to the borderline significances of the difference between the regression parameters and their theoretical values. In light of the nonsignificance of the other test for the bias and the small magnitude of both the intercept (-0.012 gal/h) and the bias (-0.005 gal/h), these are probably not of major importance.

4. Petro-Tite Method

The Petro-Tite method was tested under 18 simulated leak rates, of which three were zero rates, corresponding to a tight tank situation. While the usual Petro-Tite test takes an average of four leak rates each reported over a 15-min period, only five of these determinations were based on an hour's data. The remaining leak rates reported were each based on a 30-min test.

From all the tests, the bias was estimated at -0.05 gal/h but was smaller (0.040 gal/h) when restricted to the hour-long tests. The bias from the complete set of tests is significantly different from 0 at the 5 percent level but not at the 1 percent level. If attention is restricted to the 1-h tests, the bias is not significantly different from 0. The intercept is not significantly different from 0, suggesting that the bias is not statistically significant. The slope does not differ significantly from the ideal or theoretical value of 1 at the 5 percent significance level. The R for the regression was 75.9 percent and the standard error of the regression was 0.101. This standard error is interpreted as the precision of a single leak rate determination. It should be noted that the normal test with four 15-min rate determinations should be somewhat more precise than what was reported, and that precision could be improved further by testing for a longer period of time and averaging more individual leak rates reported.

5. Helium Detection Method

Two tests were conducted using the helium detection method. In the first test the tank was tested in its original state. Several large leaks were discovered during the first day's testing, which were repaired. The next day's test revealed substantial reduction in helium loss.

While some helium was detected around the tank, the amounts were generally very small and could have come from pipe fittings or the tank bungs. Low levels were, however, encountered in one area. The concrete was removed for inspection purposes to see if a line was located in that area. None was found, but helium levels in the excavation were moderate.

The basic problem encountered using the helium detection method is that helium can escape in measurable quantities through threaded connections which have been poorly coated with sealer. Gasoline will not normally pass through these poorly sealed connections at measurable rates under normal operating conditions. This can lead to results which are hard to interpret. In addition, no quantitative results can be produced.

C. Conclusions

As a result of the preliminary testing in Kansas City, the ARCO, Leak Lokator and Petro-Tite methods were selected for further evaluation. The helium method was dropped because of the decision that a quantitative method presented a better option for the national survey. The Certi-Tec method was dropped because of the prototype state of development and its relatively lower performance.

IV. DEVELOPMENT STUDY TESTING

A. Experimental Procedures

Five facilities were selected by the EPA for tank testing. A total of 13 tanks were tested. The initial plan was for each tank to be tested by all three methods. Difficulties in scheduling and plumbing problems at some sites, however, precluded a complete round of testing.

Two types of tests were conducted at each sites: baseline tests which were conducted in the same manner as if no evaluations were being conducted, and leak simulation tests which consisted of measuring leaks under a variety of simulated leak rates (usually four). The process was nearly identical to that described for the preliminary testing.

Three sets of data from the development study were analyzed: baseline test data; leak simulations; and time series analysis of the ambient volume fluctuations after the simulated leaks were removed.

The baseline data for each method was tabulated and compared for each tank where more than one method was used to test the same tank. Where differing conclusions regarding the tightness of the tank were obtained, the data and conditions of the test were further examined in an effort to resolve the conflict.

The data from the leak simulations were analyzed by fitting a linear regression to the data from each tank and method by regressing the reported leak rate on the simulated leak rate. The intercept of this regression represents an estimate of the leak rate of the tank or tanks system when there is no simulated leak. The difference between the intercept of the regression line and the test result from the baseline test provides an estimate of bias or accuracy of the test. The variability of the data about the regression line provides an estimate of the precision of the test. Combining these two measures yields an estimate of the mean square (or root mean square error) associated with the testing method.

The third analysis consisted of a time series analysis of the ambient volume fluctuations after the simulated leaks were removed.

B. Results

1. ARCO Method

The ARCO method was used to test seven tanks during the development study. Of these seven tanks, one tank had only the baseline test run, one tank test resulted in the baseline test and one simulated leak rate, and the other five tank tests all had the baseline leak rate and several simulated leak rate tests.

The baseline test results for ARCO are summarized in Table 3. The ARCO result disagreed with the conclusion for three tanks. However, it must be noted that the ARCO system tested tanks approximately 75 percent full, under no additional head pressure. Thus, the ARCO system provides a test most representative of the usual operating conditions of the tank. If a tank system has a hole in or near the top or fill pipe, or if there is a leak in the lines, this would not result in product leaking under normal operating conditions. While it may be unlikely that all of the leaks encountered during the study are in the top of the tank, it is a possible explanation.

A summary of the results from the leak simulation tests using the ARCO method are summarized in Table 4. By this method of testing, none of the tanks tested were reported to be leaking. However, other test methods gave different results for some tanks.

The data indicate, however, that the ARCO test method performed well at the Damneck and Pitstop North test locations. If a single data point that appears to be an outlier is removed, the method also does reasonably well at the Langley facility. One of the sites (Scott Tank 18) showed essentially no regression of the reported leak rates on the simulated leak rates. This is disturbing because for that test the method could not quantify leak rates under the simulation. One other test, at Fort Lewis, gave a slope substantially different from 1, which indicates that an (unknown) interfering factor is present.

The ARCO method gave a precise determination of a leak rate under some operating conditions. In other cases, it failed to give valid results for reasons that were not understood. In other cases, it failed to give valid results for reasons that

Table 3. Summary of Baseline Results and Tank Tests Attempted

Facility and tank	ARCO	Leak Lokator	Petro-Tite	MRI conclusion
Damneck	+0.02 C[a]	-0.077 N[b]	+0.003 C	Tight
Pitstop				
1 (south)	+0.02[c] C	-0.741 N (Poor sensitivity)	-2.892 N	Leak
2 (north)	0.0 C	-0.012 C	-0.05 C	Tight
Scott				
1 (17)	Out of time	-0.299 N	+0.004 C	Tight[e]
2 (18)	+0.02[c] C	-0.178 N Problem, possibly manifolded	-0.812 N	Leak[e]
Ft. Lewis				
1 (8C25 north)	-0.04 C	Leak about gasket-could not test	--	Tight
2 (8C25 south)	0.0[c] C	-0.027 C	-0.342 N	Leak
3 (4194)	--	-0.172 N (Poor sensitivity)	-3.0 N	Leak
4 (10E10)	--	-0.191[d] N	-0.024 C	Tight
Langley				
1 (HS tank 3)	--	-0.448 N	--	Leak
2 (HS tank 5)	Physical problem with tank	-3.0[d] N	--	Leak
3 (MoGas)	-0.03 C	--	--	Tight
4 (Golf course)	--	--	-2.540 N	Leak

[a] Certifiable.
[b] Noncertifiable.
[c] Test OK, but leak (possibly in upper part or piping) not found.
[d] Test appeared OK, but data are inconsistent.
[e] Interactive effects between Tanks 17 and 18 were observed by Leak Lokator
- (negative sign) indicates leak out.
-- indicates testing was not conducted at that tank by the test company indicated.

Table 4. Results of Leak Simulation Tests Using ARCO Method

Tank	Baseline rate	Intercept	Bias	Slope	SE	RMS
Damneck	0.02	-0.023	-0.003	1.049	0.022	0.023
Pitstop south	0.02	-	-	-	-	-
north	0.0	-0.092	-0.092	0.809	0.041	0.101
Scott 18	0.02	-0.145	-0.165	-0.044	0.099	0.192
Fort Lewis						
8C25 south[a]	0.0	-0.005	-0.005	1.140	-	-
8C25 north	-0.04	-0.094	-0.054	0.493	0.047	0.072
Langley						
MoGas	-0.03	-0.336	-0.306	0.419	0.367	0.478
	-0.03[b]	-0.027	0.003	1.167	0.118	0.118

Negative = Leak out
Positive = Leak in
Bias = Intercept - base

[a] Two points only.
[b] Outlier removed.

were not understood. It can detect inflow or outflow, but would be defeated if the water table were at a level that approximately balances the hydrostatic pressure of the product. It is also subject to interference from wind and is sensitive to vibration. It has the advantage of not requiring an overfilled tank, but this is counterbalanced by the disadvantage of not being able to detect potential leaks in the upper quarter of the tank.

The ARCO method was not recommended for use on the national survey program for several reasons. The primary reason was the decision to test the entire tank. Secondary reasons were the sensitivity of the method to interference from vibration and the relatively high frequency of tests that did not adequately quantify the simulated leak rates.

2. Leak Lokator Method

The Leak Lokator method was used to test 10 tanks during the development study. Of these, two tanks had only baseline tests and no simulated leak tests conducted. The baseline test results are summarized in Table 5. The Leak Lokator test conclusions agreed with MRI's conclusion in 6 of the 10 tank tests. Of the other four, the Leak Lokator test failed to certify three tanks that had been concluded to be tight based on data from all test methods and certified one tank that had been determined to be leaking.

A summary of the results from the leak simulation tests using the Leak Lokator method is presented in Table 5. The RMS errors ranged from about 0.02 gal/h to 0.44 gal/h. The standard errors ranged from 0.015 to 0.304. Among the tanks judged to be tight, the standard errors ranged from 0.015 to 0.165 and the RMS error ranged from 0.021 to 0.437. The large values for the upper

Table 5. Results of Leak Simulation Tests Using Leak Lokator Method

Tank	Baseline rate	Intercept	Bias	Slope	SE	RMS
Damneck (@ 120")	-0.0775 @ 125 (+0.008 @ 118)	-0.0825 (-0.005)	-0.005 (-0.13)	0.786	0.025	0.0255 (0.028)
Pitstop south	-0.524	-	-	-	0.209	-
north	-0.012	-0.026	-0.014	0.879	0.015	0.021
Scott 17	-0.299	-0.366	-0.067	0.839	0.048	0.082
18[c]	-0.178	-	-	-	0.047	-
Fort Lewis						
8C25 south	-0.027	-0.010	0.017	0.734	0.097	0.099
4194	-0.171	-0.159	0.013	0.749	0.026	0.029
10E10 NTC[a]	-0.191	-0.596	0.405	0.541	0.165	0.437
TC[b]	-0.191	0.069	0.260	0.835	0.098	0.278
Langley						
HS 3	-0.448	-0.641	-0.193	-1.78	0.048	0.199
HS 5	-3 or more	0.126	0.126	2.43	0.304	0.329

Negative = Leak out
Positive = Leak in
Bias = Intercept of their (adjusted for base) regression
Intercept = Bias plus base

[a] NTC - not temperature corrected.

[b] TC - temperature corrected by Leak Lokator.

[c] Leak Lokator observed interactive effects between Tanks #17 and #18 during the testing of #18. The reasons for this are not understood.

end of the range are from a test that had problems. If that data point is excluded, the upper end of the ranges becomes 0.048 and 0.082. With the ability of Leak Lokator to obtain multiple leak rate determinations fairly rapidly (about one every 10 to 15 min), one could presumably reduce these error estimates by making several leak rate determinations at a tank and averaging them.

The Leak Lokator method gave valid estimates of leak rates in most cases. The variability of a single leak rate measurement tends to be somewhat large relative to a 0.05 gal/h criterion, but the ability of the system to obtain leak rate determinations in about 10 min once the test is running would allow multiple determinations and averaging to reduce this variability. The method has the advantage that its level monitoring system can be used at any desired level (head pressure). Thus, if line leaks are a problem, the testing could, in principle, be conducted using a level below the piping to determine the location of the leak.

The hydrostatic pressure from a water table could pose a problem for this test. Testing did not appear to be standardized to any specific product level. Since the leak rate through a given aperture would change with head pressure, testing different tanks at different levels makes leak rate determinations difficult to compare and quantify.

3. Petro-Tite Method

The Petro-Tite method was used to test nine tanks during the development study. The locations of these tank systems and reported leak rates were given in Table 3. Three of the systems tested had leak rates so large (in excess of 5 gal/h) that simulation of additional leak rates on the order of 0.2 gal/h was not feasible. Simulated leak rate testing was performed on five tank systems.

The baseline tests conducted by Petro-Tite agree with the conclusions reached by MRI based on analysis of all the data. It should be noted that in some cases (e.g. Ft. Lewis #1) where other testers experienced difficulties, Petro-Tite would have also had difficulty.

A summary of the results from the leak simulation tests using the Petro-Tite method is presented in Table 6. The RMS errors ranged from 0.036 to 0.193 for tanks judged to be tight. The 0.193 is rather large, but that tank posed special problems, leading to the conclusion that the 0.193 is not representative. Error estimates on tanks judged to be leaking were larger, ranging up to 0.24 gal/h. Larger errors are to be expected for systems with large leaks because large leaks make it difficult to maintain product level and so therefore to obtain an accurate volume. However, the errors remained acceptably low relative to the associated leak rates.

As a result of the more detailed analysis of Petro-Tite data, several suggestions for improving the errors involved in the Petro-Tite method were developed. None of these involve significant procedural changes. Improved algorithms could likely result in better test results.

The Petro-Tite method seems capable of identifying and successfully dealing with many types of interferences in tank testing. Although there are situations that can lead to invalid test results, for the tanks tested in this study all tests but one were believed to be valid. However, difficulties were encountered that increased the error associated with the estimated leak rates beyond that which is desirable. In

Table 6. Results of Leak Simulation Tests Using Petro-Tite Method

Tank	Baseline rate	Intercept	Bias	Slope	SE	RMS
Damneck	+0.003	-0.009	-0.012	1.01	0.052	0.054
Pitstop south	-2.89	-	-	-	0.240	-
north	+0.050	+0.069	+0.019	1.26	0.078	0.075
Scott 17	+0.004	+0.002	-0.002	1.075	0.036	0.036
18	-0.812	-0.774	0.038	0.608	0.109	0.115
Fort Lewis						
8C25 south	-0.342	-	-	-	0.107	-
4194	-3.0	-	(Could not fill tank)		-	-
10E10	-0.024	-0.038	-0.014	1.50	0.193	0.193
Langley golf course	-2.54	-	(Could not keep filled)		-	-

Negative = Leak out
Positive = Leak in
Bias = Intercept - base

difficult cases, the error rates were such that one could not reliably detect leak rates as small as 0.05 gal/h. Most of the situations with large error estimates were cases where a substantial leak was present, and hence the loss in precision did not interfere with the detection of the leak.

4. Time Series Analysis of Ambient Noise Data

Because the data obtained from ARCO was not sufficient, time series analyses were performed only on the Leak Lokator and Petro-Tite data.

a. Description of Ambient Noise Analysis

The second analytical approach was to remove the simulated leaks from the data to produce volume, temperature, and temperature compensated volume time series that were longer than normally used during a tank test. These data were analyzed to determine whether the results obtained during a standard tank test period (i.e., a baseline test) were consistent with longer test times and to determine whether the temperature-estimated volume changes required for compensation adequately accounted for the total volume changes in a non-leaking tank.

Petro-Tite Method

Continuous time series of the change in volume and the change in temperature (converted to volume using the product volume and the coefficient of thermal expansion) for an entire day of Petro-Tite testing were generated from the data collected every 15 min by subtracting the simulated leak volume from the measured volume. The volume change used for this 15-min interval was an average of the volume changes observed before and after this period. Cumulative time series of volume, temperature, and temperature-compensated volume were then generated for analysis. The temperature-compensated time series were generated by subtracting the temperature (expressed in volume) from the measured volume on a point-by-point basis. This is the same method used by Petro-Tite. A least squares line was then fit to each of the three time series to estimate the mean rate of change of volume, temperature, and temperature-compensated volume. The temperature-compensated volume was compared to the baseline test results. The standard Petro-Tite data analysis method was used to estimate the temperature-compensated volume rate for the baseline tests (i.e., sum of the temperature-compensated volume computed for four 15-min periods).

Leak Lokator Method

Time series of the cumulative volume and cumulative temperature were generated for each simulated leak sequence of the Leak Lokator data. Each time series ranged from a total of 40 min to over 100 min and included four to nine of the standard Leak Lokator volume rate measure periods. The simulated leak rate was subtracted from the uncompensated volume rate measurements made by Leak Lokator and converted to volume using the reported measurement time. These volume measurements were then summed to obtain the cumulative volume time series. The mean volume rate for each simulated leak sequence was taken from the Leak Lokator data sheets. A continuous time series of temperature was generated each day of testing from annotated readings of temperature made every 5 to 10 min and placed on the strip chart of temperature by Leak Lokator personnel. Those sections of the temperature time series which bracketed the volume data for each simulated leak sequence were used in the analysis to compensate for temperature. The temperature data was converted to a volume time series and a least squares line was fit to the data to estimate the average rate of change of volume caused by the rate of change of temperature over an hour. A mean temperature-compensated volume rate was then computed for each simulated leak period by subtracting the mean rate of change of temperature from the mean rate of change of volume and compared to the results from the baseline test and the other simulated leak test sequences.

b. Petro-Tite Ambient Noise Analysis Results

A summary of the mean and 95 percent confidence intervals on the mean volume rate, temperature rate, and temperature-compensated volume rate estimated from the long Petro-Tite time series is presented Table 7. The rates were obtained by fitting a least squares line to each time series. The confidence intervals are based on the standard deviation of the ordinate about the regression line. The site, tank number, number of 15 min data points, and the test result using Petro-Tite's 0.05 gal/h detection criterion are also given. For comparison, the baseline test result is added to the table. Agreement between the baseline test results and the long time series results is good, except for Pitstop Tank No. 2. The time series from the Fort Lewis Tank No. 4 indicate that a potential leak began several hours after the test had begun.

The time series of volume, temperature, and temperature-compensated volume were generated by removing the simulated leaks from the Petro-Tite volume time series. The time series are 3 to 6 times longer than the standard 1 h Petro-Tite test. The first hour of each time series contains the baseline data. Several

Table 7. Summary of the Petro-Tite Analysis

			Volume rate (gal/h)		Temperature volume rate (gal/h)		Temperature-compensation volume rate (gal/h)		Baseline test results		
Location	Tank	N	$\bar{x}$	95% CI	$\bar{x}$	95% CI	$\bar{x}$	95% CI	Test result	Temperature-compensated volume rate (gal/h)	Test results
Damneck	1	20	0.043	0.008	0.064	0.008	-0.021	0.003	Tight	+0.003	Tight
Fort Lewis	2	7	-0.287	0.036	0.084	0.038	-0.371	0.050	Leaking out	-0.0342	Leaking out
Fort Lewis	4	22	-0.025	0.022	0.017	0.025	-0.042	0.027	Tight	-0.024	Tight
	4[a]	9	0.023	0.035	-0.051	0.133	0.074	0.117	Leaking in[c]		
	4[b]	13	-0.104	0.027	-0.006	0.040	-0.098	0.435	Leaking out		
Pitston	2	19	0.151	0.010	0.013	0.009	0.133	0.011	Leaking in	-0.05	Tight
Scott AFB	1	24	0.184	0.017	0.190	0.014	-0.006	0.005	Tight	0.004	Tight
Pitstop	1	8	-2.493	0.139	0.279	0.061	-2.773	0.089	Leaking out	-2.892	Leaking out
Scott AFB	2	16	-0.714	0.024	0.009	0.005	-0.722	0.028	Leaking out	-0.812	Leaking out

[a] First 2.25 h of the test.
[b] Last 3.5 h of the test.
[c] Direction of flow only; not statistically significant from zero.

observations about the strengths and weaknesses of the method can be made from the data.

First, the time series for Damneck Tank No. 1 and for Scott Air Force Base Tank No. 1, tanks declared to be tight, illustrates the high correlation between the low frequency trends of the temperature and volume data required for temperature compensation. This suggests that the method of temperature compensation, circulation of the product and measurement of the rate of change of temperature with one temperature sensor, is a reasonable approach.

Second, negative, high-frequency correlations were observed between the temperature and temperature-compensated volume rate time series for some of the tests. This suggests that the method is overcompensating for temperature effects. These high-frequency temperature fluctuations are probably caused by inadequate resolution of the Petro-Tite temperature sensor. This increase in the high-frequency fluctuations in the temperature-compensated volume data can be a problem if the test time is too short.

Third, inspection of the temperature-compensated volume rate time series for each test suggests that a one-hour test is too short to reliably detect small leaks. Within a test, fluctuations with period of 30 to 90 min are observed which are sufficiently different from the low frequency trend exhibited by the entire time series.

Fourth, the time series for the tests conducted on Fort Lewis Tank No. 2, Scott Air Force Base Tank No. 2, and Pitstop Tank No. 1 indicate that the tanks are leaking. The measured temperature changes are too small to account for measured volume changes.

c. Leak Lokator Ambient Noise Analysis Results

A summary of the mean and 95 percent confidence intervals on the mean volume rate, temperature rate, and temperature-compensated volume is presented in Table 8. The site, tank number, duration of the test sequence, the number of Leak Lokator volume rate measurementss in the test sequence, and the test result based on Leak Lokator's 0.05 gal/hr criterion are also given. For comparison, the baseline test results are also shown. Several observations about the data presented in Table 8 are noteworthy. First, the test sequence results for each tank tested are internally inconsistent. The results from five of the six tanks tested could be declared tight or leaking depending on which data sequence was used. The results of the other tank test (Ft. Lewis, Tank #3) indicate that the tank is leaking but cannot determine whether the flow is into or out of the tank. Second, temperature, volume, and temperature-compensated volume rate data exhibit a large range of variability compared to 0.05 gal/hr. The high variability in the temperature compensated volume rate suggests that the test time is too short and a single thermistor is not adequate for measuring the mean temperature change in the tank. These conclusions are based on the raw Leak Lokator data and an analysis similar to that used by Leak Lokator except (1) an average of four to nine standard Leak Lokator volume rate measurements were used instead of one and (2) the average rate of changes of temperature over one hour was determined by fitting a least squares line to 5 to 10 temperature values over the hour instead of the two end points. The uncertainty in the Leak Lokator temperature-compensated volume rate results presented in Table 8 is about a factor of five smaller than the uncertainty of a single 10 min volume rate measurement and a two-point temperature rate measurement.

Table 8. Summary of Leak Lokator--10-min Weighted Sample Analysis

Location	Tank	Test sequence	Total time (min)	N	Volume rate (gal/h)		Temperature volume rate (gal/h)		Temperature-compensation volume rate (gal/h)		Test result
					$\bar{x}$	95% CI	$\bar{x}$	95% CI	$\bar{x}$	95% CI	
Damneck	2	Baseline	1		-0.077						Leaking out
		1	101	8	-0.051	0.004	-0.011	0.007	-0.040	0.008	Tight
		2	112	9	-0.015	0.007	-0.052	0.011	0.037	0.013	Tight
		3	93	8	0.043	0.027	-0.041	0.005	0.084	0.027	Leaking in
		4	59	5	-0.028	0.010	-0.023	0.011	-0.005	0.015	Tight
Fort Lewis	2	Baseline			-0.027						Tight
		1	44	4	0.017	0.014	0.215	0.059	-0.198	0.061	Leaking out
		2	25	3	-0.044	0.028	0.096	0.096	-0.140	0.100	Leaking out
		3	40	4	0.019	0.020	0.001	0.026	0.018	0.032	Tight
Fort Lewis	3	Baseline			-0.172						Leaking out
		1	37	5	-0.130	0.012	0.043	0.004	-0.173	0.013	Leaking out
		2	35	5	-0.089	0.031	-0.001	0.010	-0.088	0.032	Leaking out
		3	43	7	-0.042	0.020	-0.104	0.041	0.062	0.046	Leaking in
Fort Lewis	4	Baseline			-0.191						Leaking out
		1	56	6	-0.203	0.052	-0.251	0.041	0.048	0.066	Tight
		2	41	6	0.157	0.068	-0.031	0.014	0.188	0.070	Leaking in
		3	41	5	0.158	0.034	-0.003	0.010	0.161	0.036	Leaking in
Pitstop	2	Baseline			-0.012						Tight
		1	48	7	0.096	0.009	0.079	0.033	0.017	0.035	Tight
		2	44	4	0.053	0.005	0.006	0.078	-0.003	0.079	Tight
		3	47	6	0.054	0.007	0.057	0.078	-0.003	0.079	Tight
		4	56	5	0.053	0.005	0.221	0.045	-0.168	0.045	Leaking out
Scott AFB	1	Baseline			-0.299						Leaking out
		1	55	6	-0.323	0.029	-0.262	0.075	-0.061	0.080	Leaking out
		2	44	6	-0.225	0.008	0.032	0.008	-0.193	0.011	Leaking out
		3	56	5	-0.241	0.005	-0.008	0.024	-0.233	0.024	Leaking out
		4	36	5	-0.206	0.0374	0.008	0.014	-0.214	0.040	Leaking out

The time series plots of temperature (converted to volume) and uncompensated volume were generated for each of the 21 sequences of Leak Lokator data. These cumulative time series plots illustrate the reasons for the inconsistent test results and the high variability. The volume and temperature time series, and the least squares line fit to the temperature data are presented in the report, "Development of a Tank Method for a National Survey of Underground Storage Tanks."[4]

Some difficulty is evident in using a two-point analysis approach. Depending on which two points are taken, a positive, nearly zero, or negative slope can be determined because of the large fluctuations in temperature.

C. Recommendations for the National Survey Testing

The findings of the development study have resulted in several recommendations concerning the method of tank testing to be used in the national survey program. These recommendations are summarized below.

- **The tank testing method should include putting a head of pressure on the tank.** There are two reasons for this. First, proper compensation for water table effects are necessary if the proper conclusion is to be reached under high water table conditions. Second, this process enhances the flow of product through small holes, making them more likely to be detected, particularly if they are near the top of the tank.

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[4] See Footnote 1.

- **The tank test method should provide frequent temperature measurements with a precise thermistor and adequate temperature compensation. The product should be circulated or mixed during the test.** Adequate temperature compensation is a key to successful interpretation of tank test data. Such data must consist of accurate temperature measurements at frequent intervals. The judgment to mix is a choice of techniques which is associated with the better performance achieved by the single thermistor approach used by Petro-Tite over the single thermistor approach used by Leak Lokator.

- **Data on temperature and level changes must be collected frequently.** This is necessary to minimize aliasing of the high frequency fluctuations (out of the signal band) into the lower frequencies (in the signal band). This conclusion is based large on data analysis performed by Vista Research, Inc.[5]

- **Data collection must continue for an adequate period of time so that sufficient data for a precise analysis can be provided. A minimum of 4 to 6 hours with frequent temperature and tank level change intervals is needed.** While a test length of 4 to 6 hours with frequent temperature and level readings is desirable, the practical considerations of cost and disruption to an establishment are also factors.

- **The test method must incorporate an adequate statistical analysis of the data to draw supportable conclusions about the leak rate.** None of the techniques were found to collect either sufficient test data or to provide adequate analysis algorithms. Improved analysis protocols will be required.

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[5] "Analysis of the Pilot Study Tank Test Data," Vista Research, Inc., July 1985.

V. PILOT STUDY

A. Objectives

The results from the earlier stages led to the recommendation that a test using modified Petro-Tite equipment and procedures be adopted for the national survey. The major objective of this final stage was to modify and evaluate the performance of the Petro-Tite method as it was to be used on the national survey. This process included:

- Determining the best sampling interval for collecting the data; that is, the time interval at which product in the standpipe should be re-leveled and data readings made;
- Determining the best length of the test;
- Developing and testing the analysis algorithm;
- Implementing the procedures operationally in the field to identify operating difficulties and correct them;
- Field testing the entire survey data collection effort including scheduling, data collection, and analysis;
- Estimating the detection performance of the method; and
- Finalizing the test protocol.

B. Overview

A sample of 25 tanks was selected from two primary sampling units (PSUs) on the west coast for use in the pilot study. The owners and operators of these tanks were contacted to arrange for the tanks to be tested and to schedule the tests. Timing of the contacts and arrangements for fuel delivery, payments, and scheduling presented difficulties. Recommendations for mitigating these on the national survey were developed. Notifying owners earlier of the test and giving a longer lead time to arrange and schedule the tests were found to be necessary to expedite testing.

Data were collected at three different time intervals and for three different total time periods. The resulting data were analyzed by various methods to select the most practical and effective data collection interval and test length. A standard data analysis protocol was developed for use when no testing or data problems are identified. Data management procedures for the national survey were developed which included the use of on-site computers to collect data. Data and test review procedures were developed to check each tank test for validity and to ensure that the standard analysis was adequate. A simplified analysis that can be used in the field to visually inspect the data and identify potential testing problems was developed and implemented. The tank test data were analyzed and a data report prepared and submitted to EPA.

C. Data Collection

Data identifying the tank, size, location, product, etc., were entered onto the top of a spreadsheet data file utilizing a portable computer. Then test data are entered as each data point becomes available. This provided a preliminary analysis and estimated volume change rate that can be obtained on the scene.

D. Data Analysis

The data from the pilot study tank tests were analyzed with two objectives. One was to determine the best sampling interval, and the second was to determine the best total test duration. Sampling intervals of 1, 5, 10, and 15 minutes were considered. Data collection at 1-min intervals was found to be impractical for the large scale survey. Both the 5- and 10-minute intervals provided improvements in the precision of the test data, but the 5-minute interval resulted in better precision. Thus, data collection at 5-minute intervals was selected as the standard. This analysis is presented in detail in Vista Research, Inc.'s report.[6]

Selection of the total time of the test was not so clear-cut. Longer test times were desirable from a data quality standpoint, but practical limitations were also considered. A compromise of 2 hours of data at the low level was selected as providing sufficient data while still proving to be practical for the field data collection.

The test protocol used the same equipment as for a standard Petro-Tite test. There were no changes in the test procedures except for the sample interval and length of the test.

The analysis algorithm was modified to include smoothing of the temperature data before applying the temperature correction. A regression line was then fitted to the corrected data to obtain the leak rate.

Seventeen tanks were tested in the pilot study. A summary of the test results is presented in Table 9.

A family of performance curves was generated for the large and small tanks to estimate detection performance for a given leak rate as a function of probability of detection, probability

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[6] Ibid.

Table 9 Summary of Pilot Study Results

Site no.	Tank no.	System leak rate (gal/h)	Standard Error (2 h) (gal/h)	OHM rate (gal/h)	Conclusion	Fuel	Tank size (gal)
1		0.036	0.0074	+0.037	C	UNL	11,907
2	T1	-0.036	0.0098	-0.038	C	UNL	1,034
2	T2	-1.381	0.0490	-1.518	N	D	7,896
2	T3	-0.263	0.0138	-0.367	N	D	7,896
2	T4	0.009	0.0107	+0.015	C	D	10,152
3		-0.012	0.0242	+0.032	C	PUNL	1,036
4		+0.294	0.0601	+0.256	N(I)	UNL	10,152
5	T1	0.026	0.0114	0.042	C	D	10,152
5	T2	-0.107	0.0041	-0.115	N	D	10,152
5	T3	+0.054	0.0047	-0.005	C	UNL	10,152
6		-0.008	0.0137	-0.024	C	UNL	8,000
7	T1	0.036	0.0245	+0.016	C	LR	6,006
7	T2	0.042	0.0307	+0.096	N(I)	LP	6,006
7	T3	0.013	0.0348	+0.031	C	UNL	6,006
8		-0.056	0.0067	-0.029	N	D	10,383
9	T1	-0.010	0.0098	+0.028	C	UNL	1,036
9	T2	-0.015	0.0130	-0.008	C	LR	1,036

C = Certifiable by NFPA standard.
N = Not certifiable (I) Inconclusive test
D = Diesel
UNL = Unleaded
PUNL = Premium unleaded
LR = Leaded regular
LP = Leaded premium

of false alarm, and test time. Detection performance for 0.05 gal/h leaks was unacceptable. A test period of 1 hour or less is too short to achieve reasonable detection performance. For the small tanks, test times of 1, 2, and 3 hours result in the detection of 0.10, 0.075, and 0.05 gallon per hour leak rates with a P_D = 95 percent and a $P_{FA} < 5$ percent. For the large tanks, test times of 1 and 2 hours result in the detection of 0.25 gal/h leak rates with a P_D = 95 percent and a P_{FA} = 2 percent and 5 percent, respectively.

Of the 17 tanks tested, one resulted in a clearly invalid test. One test was problematical, but the system is probably tight. Three tanks appear to have significant leaks, and the remainder appear to be tight. Due to the fact that the Petro-Tite method places a higher head pressure on the tank than is found in normal operation, the reported rates are overestimates of product loss or leakage in operation.

Since the pilot study data available for analysis was somewhat limited, the determination of the detection limit of the Petro-Tite method could not be established as well as hoped. Further data from the national survey will need to be examined.

VI. RECOMMENDATIONS FOR NATIONAL SURVEY

The recommendations for the national survey are:

1. Use a modified Petro-Tite test method;
2. Data should be collected at 5-minute intervals for 2 hours at each tank; and

3. Data analysis should use improved algorithms to fit data which exhibit curvilinearity in the test results.

The final proposed equipment configurations and data collection, environmental measurement, and data analysis procedures which resulted from the development and pilot studies were specified in a separate document.[7] The actual procedures and methods which were followed in the field are documented in Sections 6 and 7 and Appendix D of this report.

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[7] "National Survey of Underground Storage Tanks: Draft Test and Analysis Plan," Midwest Research Institute, June 10, 1985.

APPENDIX D

TANK TESTING DATA REDUCTION AND STATISTICAL ANALYSIS LEADING TO LEAK STATUS DETERMINATION

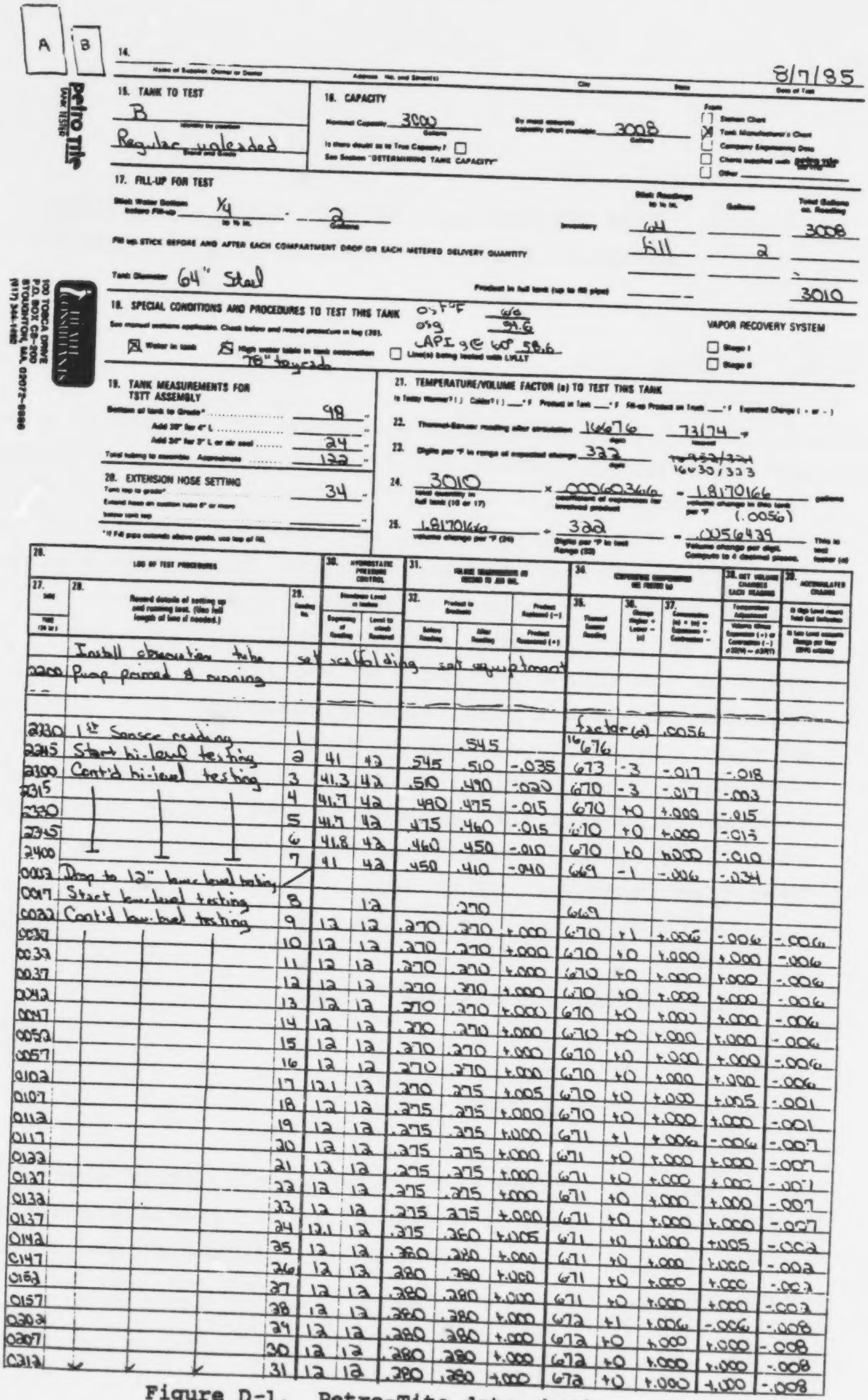
I. INTRODUCTION

This appendix contains additional detail and in some cases a more technical presentation of topics covered in Sections 7 and 8 of the report. Parts II and III of this appendix provide further details on the tightness test raw data and the initial reduction steps which produced the basic volume change rate estimates and the estimated within-test standard errors for these estimated rates. Part IV provides further detail on the retest results, which is summarized in Part V of Section 7. Part V of this appendix provides a more technical description of the estimation of total test variance than is given in Section 8. Part VI provides a more technical description of the leak status determination rule than appears in Part III of Section 8, and Part VII gives more details on the adjustment to test pressure than appears in Part II of Section 8.

I. DATA COLLECTION AND MANAGEMENT

A. Data Collected

The tank testing data collected consist of several data elements. A sample of a typical Petro-Tite data sheet is displayed as Figure D-1. Identifying information about the site, tank system, and product were determined and entered as header



A B

petro tite TANK TESTING

HEATH CONSULTANTS
100 TOSCA DRIVE
P.O. BOX CS-200
STOUGHTON, MA. 02072-8086
(617) 344-1400

14. Name of Supplier, Owner or Dealer — Address No. and Street(s) — City — State — Date of Test 8/7/85

15. TANK TO TEST

B

Regular unleaded

16. CAPACITY

Nominal Capacity 3000 Gallons

By most accurate capacity chart available 3008 Gallons

Is there doubt as to True Capacity? ☐

See Section "DETERMINING TANK CAPACITY"

From:
☐ Station Chart
☒ Tank Manufacturer's Chart
☐ Company Engineering Data
☐ Charts supplied with petro tite
☐ Other

17. FILL-UP FOR TEST

Stick Water Bottom before Fill-up ¼ to ½ in. — 2 Gallons

	Stick Readings to ½ in.	Gallons	Total Gallons on Reading
Inventory	64		3008
Fill up. STICK BEFORE AND AFTER EACH COMPARTMENT DROP OR EACH METERED DELIVERY QUANTITY	fill	2	
			-
Product in full tank (up to fill pipe)			3010

Tank Diameter 64" Steel

18. SPECIAL CONDITIONS AND PROCEDURES TO TEST THIS TANK

OSF°F 66
OSG 94.6
API g@ 60° 58.6

See manual sections applicable. Check below and record procedure in log (28).

☒ Water in tank ☒ High water table in tank excavation 78" to grade ☐ Line(s) being tested with LVLLT

VAPOR RECOVERY SYSTEM
☐ Stage I
☐ Stage II

19. TANK MEASUREMENTS FOR TSTT ASSEMBLY

Bottom of tank to Grade* 98"
Add 30" for 4" L ___"
Add 24" for 3" L or air seal 24"
Total tubing to assemble. Approximate 122"

20. EXTENSION HOSE SETTING

Tank top to grade* 34"
Extend hose on suction tube 6" or more below tank top ___"

*If Fill pipe extends above grade, use top of fill.

21. TEMPERATURE/VOLUME FACTOR (a) TO TEST THIS TANK

22. Thermal-Sensor reading after circulation 16676 digits 73/74 °F

23. Digits per °F in range of expected change 322 digits ~~16932/334~~ 16630/333

24. 3010 (total quantity in full tank (16 or 17)) × .000603666 (coefficient of expansion for involved product) = 1.8170166 (volume change in this tank per °F) gallons (.0056)

25. 1.8170166 (volume change per °F (24)) ÷ 322 (Digits per °F in test Range (23)) = .0056439 (Volume change per digit. Compute to 4 decimal places.) This is test factor (a)

26. LOG OF TEST PROCEDURES

27. Time (24 hr)	28. Record details of setting up and running test. (Use full length of line if needed.)	29. Reading No.	30. Beginning of Reading	Level to which Restored	32. Before Reading	After Reading	Product Replaced (−) / Recovered (+)	35. Thermal Sensor Reading	36. Change (d)	37. Computation	38. Net Volume Changes Each Reading	39. Accumulated Change
	Install observation tube set scaffolding set equipment											
2200	Pump primed & running											
--												
2230	1st Sensor reading	1						factor (a)		.0056		
						.545		$^{16}676$				
2245	Start hi-level testing	2	41	42	.545	.510	-.035	673	-3	-.017		
2300	Cont'd hi-level testing	3	41.3	42	.510	.490	-.020	670	-3	-.017	-.018	
2315		4	41.7	42	.490	.475	-.015	670	+0	+.000	-.003	
2330		5	41.7	42	.475	.460	-.015	670	+0	+.000	-.015	
2345		6	41.8	42	.460	.450	-.010	670	+0	+.000	-.015	
2400		7	41	42	.450	.410	-.040	669	-1	-.006	-.010	
0002	Drop to 12" low-level testing										-.034	
0017	Start low-level testing	8		12		.270		669				
0022	Cont'd low-level testing	9	12	12	.270	.270	+.000	670	+1	+.006	-.006	-.006
0027		10	12	12	.270	.270	+.000	670	+0	+.000	+.000	-.006
0032		11	12	12	.270	.270	+.000	670	+0	+.000	+.000	-.006
0037		12	12	12	.270	.270	+.000	670	+0	+.000	+.000	-.006
0042		13	12	12	.270	.270	+.000	670	+0	+.000	+.000	-.006
0047		14	12	12	.270	.270	+.000	670	+0	+.000	+.000	-.006
0052		15	12	12	.270	.270	+.000	670	+0	+.000	+.000	-.006
0057		16	12	12	.270	.270	+.000	670	+0	+.000	+.000	-.006
0102		17	12.1	12	.270	.275	+.005	670	+0	+.000	+.000	-.006
0107		18	12	12	.275	.275	+.000	670	+0	+.000	+.005	-.001
0112		19	12	12	.275	.275	+.000	670	+0	+.000	+.000	-.001
0117		20	12	12	.275	.275	+.000	671	+1	+.006	-.006	-.007
0122		21	12	12	.275	.275	+.000	671	+0	+.000	+.000	-.007
0127		22	12	12	.275	.275	+.000	671	+0	+.000	+.000	-.007
0132		23	12	12	.275	.275	+.000	671	+0	+.000	+.000	-.007
0137		24	12.1	12	.275	.260	+.005	671	+0	+.000	+.000	-.007
0142		25	12	12	.280	.280	+.000	671	+0	+.000	+.005	-.002
0147		26	12	12	.280	.280	+.000	671	+0	+.000	+.000	-.002
0152		27	12	12	.280	.280	+.000	671	+0	+.000	+.000	-.002
0157		28	12	12	.280	.280	+.000	671	+0	+.000	+.000	-.002
0202		29	12	12	.280	.280	+.000	672	+1	+.006	-.006	-.008
0207		30	12	12	.280	.280	+.000	672	+0	+.000	+.000	-.008
0212		31	12	12	.280	.280	+.000	672	+0	+.000	+.000	-.008

Figure D-1. Petro-Tite data sheet

information. Additional data needed to set up the test were recorded. These included the diameter of the tank, the depth from grade to the bottom and top of the tank, and the depth of the water table. An initial thermistor reading was taken and the internal check of the thermistor unit was performed. The specific gravity of the product was measured and used to determine the coefficient of expansion. The tank volume was determined. Presence of water in the tank was checked. If water was present, the volume of water in the tank was calculated and subtracted from the tank volume to determine the volume of product. A final adjustment to product volume was to add the volume in the test equipment (usually 2 to 3 gallons).

After the preliminary data had been entered in the header, the actual test data were taken and entered. The time of reading was entered. The reference level was noted. The volume in the graduated cylinder before releveling was found and entered. After releveling, the volume in the graduated cylinder was found and entered as "volume after." The fuel temperature in terms of the digit reading on the thermistor unit was found and entered. The actual test data used to calculate leak rates consist of the time, the volumes before and after, the temperature, the tank product volume, the digits per degree Farenheit, and the coefficient of expansion.

B. Data Management

The test data collected as described above were recorded on a Petro-Tite data sheet by the test crew. The MRI technician at the site keyed these data into a Lotus 123 worksheet file that had been configured to receive the data and perform preliminary calculations. An example printout of the data portion of this file is shown in Figure D-2. The MRI technician entered the

```
19-Aug-85                          Page 1

        Survey ID                 Fuel Type UNLEADED   Date       AUG 7 1985
 Tank   Test Firm DBL CHK         Tank Vol        3010 T digits        16676
 2 of   Test Crew               7 API Dens        58.6 T digits/F        322
      2 MRI Crew  STEVE           Exp Coef  0.00060366 Leak Rate       0.001
                                                       Std. Err    0.0058976
 Time      Level     V Before   V After    Fuel Temp    Tcorr dV  Leak Rate
Hr  Min    (div)      (gal)      (gal)     (digits)      (gal)     (gal/h)
------------------------------------------------------------------------------
 0  17        12      N/A        N/A         16669       N/A       N/A
 0  22        12      0.270      0.270       16670      -0.006    -0.068
 0  27        12      0.27       0.27        16670       0.000     0.000
 0  32        12      0.27       0.27        16670       0.000     0.000
 0  37        12      0.27       0.27        16670       0.000     0.000
 0  42        12      0.27       0.27        16670       0.000     0.000
 0  47        12      0.27       0.27        16670       0.000     0.000
 0  52        12      0.27       0.27        16670       0.000     0.000
 0  57        12      0.27       0.27        16670       0.000     0.000
 1   2        12      0.27       0.275       16670       0.000     0.000
 1   7        12      0.275      0.275       16670       0.005     0.060
 1  12        12      0.275      0.275       16670       0.000     0.000
 1  17        12      0.275      0.275       16671      -0.006    -0.068
 1  22        12      0.275      0.275       16671       0.000     0.000
 1  27        12      0.275      0.275       16671       0.000     0.000
 1  32        12      0.275      0.275       16671       0.000     0.000
 1  37        12      0.275      0.28        16671       0.005     0.060
 1  42        12      0.28       0.28        16671       0.000     0.000
 1  47        12      0.28       0.28        16671       0.000     0.000
 1  52        12      0.28       0.28        16671       0.000     0.000
 1  57        12      0.28       0.28        16672      -0.006    -0.068
 2   2        12      0.28       0.28        16672       0.000     0.000
 2   7        12      0.28       0.28        16672       0.000     0.000
 2  12        12      0.28       0.28        16672       0.000     0.000
 2  17        12      0.28       0.29        16673       0.004     0.052
------------------------------------------------------------------------------
```

Figure D-2. LOTUS data sheet

header data including the date, test crew, testing company, MRI person, and the time, level, volumes before and after, and fuel temperature (digits). The program calculated the leak rate, standard error, and other intermediate values.

After the data were entered into the computer on site, they were stored on a diskette. In order to facilitate expeditious data analysis, the data were transmitted to MRI via telephone using a modem. The diskettes containing the data files were shipped to MRI on a weekly basis. The original Petro-Tite data sheets were also shipped to MRI.

Upon receipt of the electronically transmitted data files, they were printed and the volume trends plotted. Figure D-3 shows an example of such a plot. The calculations of the leak rate and standard error were checked. Any unusual features of the data such as outliers or curvilinearity were noted. The computer file was archived as received and the hard copy was placed in an archive file. A copy of the computer file was placed in a working directory.

When the disk containing the data file was received, the disk file and the telephone file were compared using the IBM DOS utility file compare program to determine whether the data transfer was complete and accurate. If the files were found to differ, a new hard copy of the data and graph were printed.

Upon receipt of the Petro-Tite data sheets, the printed data from the computer file were checked against the raw data sheets. Any discrepancies were corrected in the computer file. If the final file differed, another hard copy of the data and graph was printed. The final form of the computer file was archived.

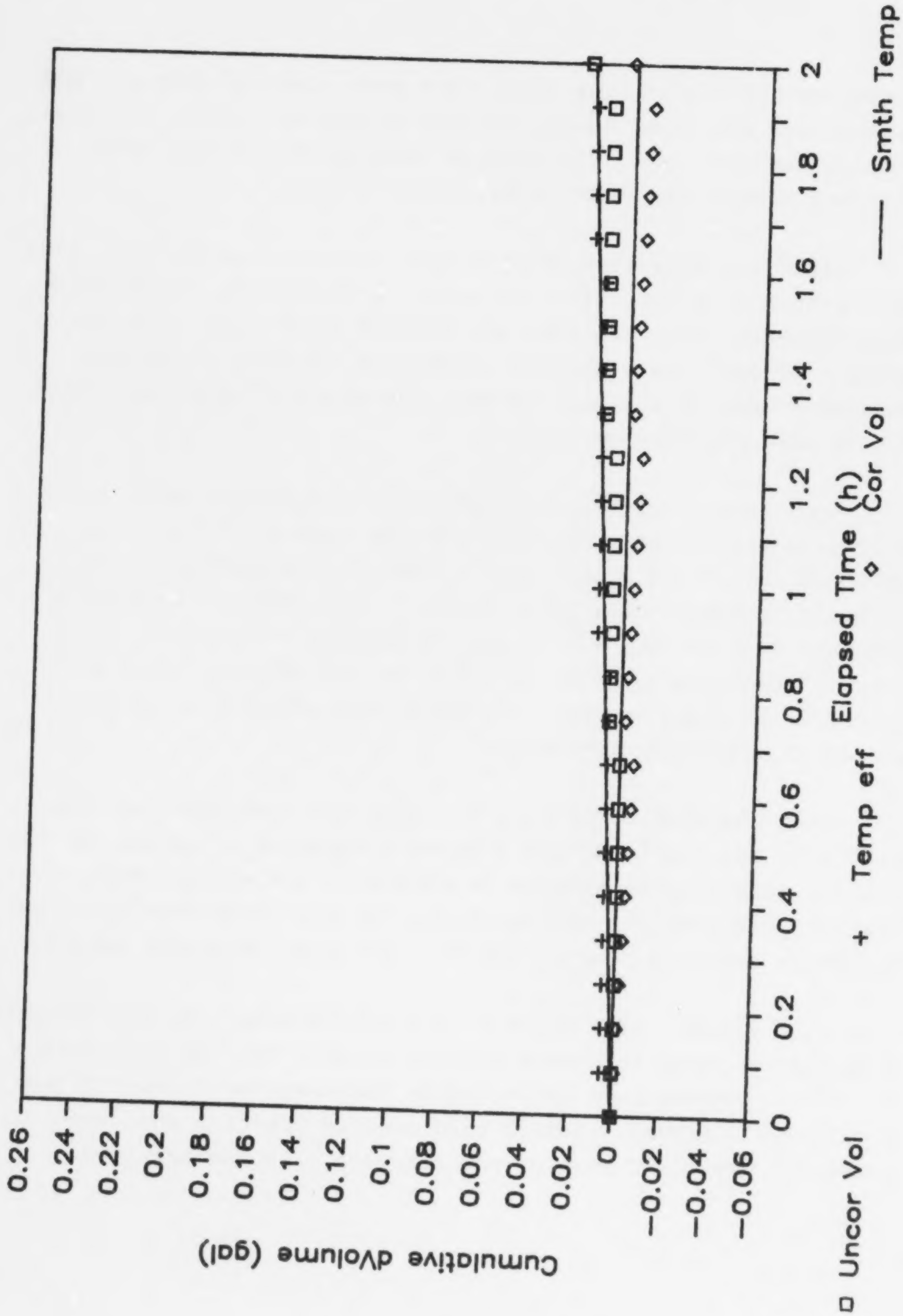


Figure D-3. Plot of data using Lotus Data File

After the data had been checked against the original sheet, the final data analysis was done for the tank or system. When the analysis was completed, a final copy of the data was printed, incorporating any special analysis with the final leak rate and standard error estimates. The final computer file was archived.

III. DATA REDUCTION ANALYSIS METHODS

A. Statistical Methods Considered and Choice

Several methods of statistical analysis of the tightness test data were considered for use on the national survey. This section presents a discussion of the advantages and disadvantages of each and gives the reasons for the selection of those used.

The test method produced a volume change measurement at 5 minute intervals. This change was measured directly by bringing the standpipe to a reference level and collecting the product recovered or measuring the additional product needed. The other measurement recorded at 5 minute intervals was a temperature measurement. This measurement was taken by means of a thermistor probe and box. To make this reading, a resistance bridge was balanced by means of a dial. The instrument reading was converted to a temperature by means of the calibration chart for the instrument. The readings--after conversion to temperature--were the temperature of the product in the tank at 5 minute intervals. The temperature record of the product as measured by the thermistor must be converted to an equivalent volume change using the volume of the tank and the thermal coefficient of expansion. One essential difference between the volume and temperature readings should be noted. The temperature was recorded as a cumulative reading--the tank temperature--while the volumes were recorded as differences.

In order to make the temperature and volume data comparable, they must be put in the same form. Either both must be changes or both must be cumulative. Several approaches can be used for the analysis. The standard Petro-Tite approach to the analysis of the data is to take differences in the temperature readings. The time interval used by Petro-Tite is 15 minutes rather than the 5 minute intervals selected for the national survey testing. After taking differences in the temperature readings, the change in temperature is multiplied by the volume of the tank and the thermal coefficient of expansion for the product to produce a volume change due to temperature. This is subtracted from the observed volume change at each point. The resulting differences are temperature-adjusted volume changes. The standard Petro-Tite analysis adds up four of these 15 minute readings to obtain the hourly leak rate that they report. An advantage of this method is its simplicity. A disadvantage is that no estimate of variability is provided. An additional disadvantage is that four 15 minute data points do not provide sufficient data to ensure that the test is valid.

A similar approach could be followed for analysis of the survey data. Consecutive temperatures could be differenced to obtain temperature changes for each 5 minute interval. This would provide a set of observed volume changes and temperature changes. The temperature changes would be converted to volume changes by use of the coefficient of expansion. At this point two different approaches to the analysis could be used.

One approach is to regard the observed volume changes and the temperature volume changes as a paired sample. In this analysis, one would calculate differences in each pair. These differences would be averaged to obtain an estimated leak rate. The variability of the differences would be used to obtain an estimate of the variability measured by the standard deviation. The variation of the mean would be estimated by the standard error of the differences (the standard deviation divided by the square root of the number of terms in the average). This would result in n-1 degrees of freedom for the standard error. Both the mean and standard error (or standard deviation) would be rescaled to an hourly leak rate.

There are a number of advantages to this approach. It is directly comparable to the standard Petro-Tite tests. It is relatively simple and should be easily understood. It does provide an estimate of variation. If the volume change and temperature changes are dependent, it accounts for this by pairing the data. In addition, if the differences were less variable than the original data, it would provide a more precise estimate than other approaches. A disadvantage is that if the data are not dependent, it sacrifices degrees of freedom unnecessarily. In addition, if pairing does not reduce variability, then this analysis would lose precision.

A slightly different approach is to regard the volume data and the temperature-volume data as two samples rather than as a paired sample. With this approach, the mean volume change would be calculated as would the mean temperature-volume change. The difference in these two means would be calculated. This would result in the same estimate of the leak rate or volume change as with the paired data. However, there would be a difference in the estimation of the variability. Each set of data--volume and temperature-volume--would have its variability estimated separately by the sample variance. If it were assumed that these variance estimates were estimating the same quantity, a pooled variance estimate could be calculated from these two. This would have a total of 2n-2 degrees of freedom, where n is the number of data points of each type. This approach has an advantage if there is no inherent dependence in the two types of readings. It also is advantageous if pairing does not reduce variability enough to offset the loss in the number of degrees of freedom.

If it were concluded that the variation of the two types of data is different, then the sample variances should not be pooled. In this case, the variance of the difference in sample means would be the sum of the two variances of the means (the variance of the mean is the sample variance divided by n). The assumption would be that n is large enough so that the sample mean would be approximately normally distributed. After the variance of the difference in the means is calculated, the square root of this number would be taken. Finally, the estimated leak rate and the standard error of it would be rescaled to an hourly leak rate as before. Thus, while the estimate of the leak rate would be the same, the estimate of the variability would differ. This approach has the same advantages of the previous approach. The essential difference is in the calculation of the variability. The choice between these two approaches should be based on whether the assumption that the temperature-related volume changes and the observed volume changes have the same variability is valid. Consideration of the precision of the two measuring instruments and of the rounding errors involved in the two measuring processes suggests that the temperature-related volume changes and the observed volume changes do not have the same variance in general. Consequently, this latter approach would be preferred.

The result that the variability in the temperature-related volume data is larger than the variability in the observed volume changes suggests that it may be advantageous to smooth the temperature data before adjusting the observed volumes for temperature. Basically, this approach would use some degrees of freedom to smooth the temperature data by fitting a curve of some sort to them prior to making the volume adjustments for temperature. It would use the fitted curve in the adjustments in order to reduce variability.

Since the temperature data as recorded represent the temperature of the tank over time, one approach is to fit a curve to these temperatures and use the expected or predicted values from the fitted curve for adjustment. In the typical test, the temperature increased smoothly in a nearly linear fashion over the period (about 2 hours) of the test. In this case, a linear regression through the origin (or the starting temperature) provides an adequate smoothing. The predicted values from the regression can be used to adjust the volume changes. In some cases, the temperature displayed a curvilinear form so that the straight line fit was inadequate. In these cases, adding a quadratic term to the regression provided a satisfactory fit. Occasionally, the temperature was not monotonic or displayed some other unusual behavior. In this event, moving averages were used to smooth the temperature-related volumes prior to adjusting the volumes.

The advantage of smoothing is that it may reduce the variability of the estimate and so improve the precision of the test. A disadvantage is that it is somewhat more complicated than a linear or quadratic fit. An additional potential disadvantage is that it may require a different form of analysis to be used depending on the temperature data. On the other hand, any method of analysis should allow for diagnostics to ensure that the data from the test meet the assumptions adequately. It should be anticipated that some tests will give data that do not meet the standard assumptions. Such tests will either be judged invalid or will require specialized analysis.

A rather different approach can be taken by cumulating the volume differences. This would provide two sets of cumulative data (one for volume, one for temperature-related volume) that can be viewed as time series. With this approach, time series models could be fit to both series. A transfer function could be used to relate the two series and form a third series of the temperature-adjusted volumes. The estimate of the temperature-adjusted volume change rate could be made from the parameters of the time series model of the derived series. This approach would have an advantage if the volume measurements and temperature measurements showed common forms of serial correlation that would leak to a particular form for a time series model in the majority of cases. There are some disadvantages of this approach. One is that a large number of data points is required in order to fit the time series models and have a sufficient number of degrees of freedom. A second is that the analysis is much more complicated and time consuming. A third is that the analysis must estimate the appropriate model form for each series. The major drawback is that time series analysis requires more data than was available from the tests in the national survey.

A spectral analysis of the data from a long test during the pilot study led to the conclusion that for test times exceeding one hour, a sophisticated time series algorithm was not necessary.

B. Standard Analysis

As a result of the considerations of the types of analyses available and the advantages and disadvantages of each, a standard analysis was designed. For the standard analysis, the temperature-related volume change and the observed volume change were both expressed in cumulative form, beginning at zero for the start of the low level (4-psig) test. A straight line through the origin was fit to the temperature-volume data by least squares. The predicted values of this line were calculated and used as a smoothed temperature correction. The data were plotted and inspected visually for outliers or deviations of the temperature data from linearity. Any questionable data were checked in detail or considered for special analysis.

If no problems with the data were found, the predicted values from the smoothed temperature line were used as the temperature correction. This smoothed temperature correction was subtracted from the observed volume data for each time point. The resulting differences were divided by the time interval to obtain a series of volume change rates expressed in gallons per hour, typically based on a 5 minute interval. The arithmetic mean of these rates was calculated and used as the estimate of the leak rate. The standard error of this mean was calculated and presented as the standard error of the estimate. In the variance computation, n-1 was used as the divisor, where n is the number of terms in the mean. The result was divided by n to form the variance of the mean. The square root of this is the within-test standard error reported before adjusting for between-test variation. (See Section D.V, below, for discussion of total variance.)

The question of the appropriate number of degrees of freedom was considered. It was possible that the terms in the mean might be correlated, implying that the actual degrees of freedom would be less than n-1. Spot checks of the serial correlation of the terms showed generally no significant (at the 10% level) correlations. For a few data sets some of the lag correlations were significant. However, this occurred in only about 20% of the data sets. Those where one or more significant correlations were found showed no consistent pattern of which serial correlations were significant. Consequently, this was interpreted as being likely to be due to chance. No adjustment of the degrees of freedom is thought necessary.

C. Special Analyses

A number of data set features called for a different or more detailed analysis than that described above. The most obvious case was that of a manifolded tank system. Within the set of manifolded systems, a slightly different analysis was needed for different numbers of tanks, and a different analysis was needed for systems tested together as opposed to those with tanks tested separately.

Manifolded tanks that were separated and tested separately provided two or more individual tank tests. As individual tank tests, these were subjected to the standard analysis (or special analysis if needed). This provided volume change rate estimates and standard errors for each tank (and its associated lines). These needed to be combined to estimate a system volume change rate. In the descriptive data presented in the first part of Section 9, the individual test results for tanks in a manifolded system were used separately when available. The multivariate analyses were restricted to single-tank systems. Thus, creating system volume change rates was done for completeness in the deliverable data file. This was done by summing the two estimates of volume change rates. The variability of this combined rate was estimated by taking the variances of the individual volume change rates and adding these. Taking the square root of this gave the standard error of the combined rate. This extends to any number of tanks in a manifolded system tested separately.

Manifold tanks tested together provided slightly different data. A single standpipe (or two connected by a siphon) was used. A single volume change was recorded for the system every 5 minutes. However, each tank had a circulation pump and the associated thermistor unit to measure temperature. In general, each tank could have a different volume, although the usual case was for tanks of the same volume to be manifolded.

A temperature-related volume change was calculated for each tank. These were summed. The result represented the total temperature-related volume change. This was used as the temperature effect. It was smoothed as before with a least squares line through the origin, and the temperature adjusted volume change rates calculated as before.

A number of other special cases were found and were dealt with on an individual basis. Occasionally apparent outliers were found. These were checked against the raw data and the test log to see if there was any physical reason for them. A few tests had thermistor boxes fail during the test for some reason (rain, FM interference). These generally gave temperature data that appeared as outliers. When outliers were found and a physical reason identified, the aberrant data were removed from the analysis. This generally required smoothing over the missing data by interpolation. If errors were identified, they were corrected and the analysis redone.

The typical data showed a monotonically increasing temperature, generally linear. A smaller proportion of the data sets showed linearly decreasing temperature. Some data sets showed evidence of temperature increase that was curvilinear. If this curvilinearity appeared or was suspected, a test for curvilinearity was done by fitting both a linear and quadratic to the temperature data by least squares (through the origin). If the quadratic improved the fit significantly, the curvilinear fit (using both linear and quadratic terms) was used for smoothing.

A few cases were found where both temperature and volume were not only non-linear, but also non-monotonic. Provided that they showed the same pattern, analysis proceeded. In this event, a five point moving mean was used to smooth the temperature data. Equal weights were used. This resulted in the loss of four data points; two at the start and two at the end of the test. The moving mean smoothed temperature volumes were subtracted from the volume changes to obtain temperature-corrected volumes. These were divided by the time intervals and expressed as gallons per hour. The arithmetic mean and standard error of these temperature corrected volume rates were calculated and used as the estimates of the volume change rate and its standard error, respectively.

Some tests showed volume change rates that were initially increasing rapidly and curvilinear, while the temperature changes were quite linear. The volumes typically increased rapidly for the first few times, then slowed. This was interpreted as relaxation of tank deformation. The apparent relaxation appeared to follow an exponential curve and to approach the temperature change rate as an asymptote. However, the constant of this asymptote differed by tank. The rate of relaxation may be related to the nature of the soil in backfill and water conditions. When this was identified, the initial points exhibiting this relaxation of the tank deformation were deleted before analysis.

D. Criteria for Invalid Data

A few of the data sets from the tank tests were judged invalid based on the analysis of the data. This occurred quite infrequently.

There were a number of criteria for declaring a data set to be invalid. The most common was that the data showed a volume increase even after adjusting for temperature. Since the test method places pressure on the tank, a volume increase cannot occur from inflow of water. Data that showed volume increases after temperature adjustment that exceeded levels that could be reasonably attributed to the variability of the measurement process were judged to be invalid tests. The reason for this is that such an apparent volume increase with no explanation could be eclipsing a small actual volume loss or leak. Generally any tank that showed a volume gain rate of more than 0.1 gallons per hour after temperature adjustment was judged to be an invalid test. The most likely explanation for such tests is that those tanks had trapped vapor pockets.

A variety of other data features led to the conclusion that the test was invalid. Some of these may also have been caused by trapped vapor. A few instances were found where the temperature as recorded fluctuated erratically during the test while the volume measurements were relatively stable. If the temperature data were so erratic as to preclude a temperature adjustment, then the test was declared to be invalid. One or two tests showed both temperature and volume measurements that were erratic and did not appear to track together. These tests were also judged invalid. Such behavior may have been caused by incomplete tank deformation, followed by relaxation, combined with mixing problems. No valid volume change rate could be estimated.

IV. RETEST RESULTS

Three types of retests were conducted as part of the national survey of underground storage tanks. One was a back to back retest, conducted immediately after the original test used to estimate the leak rate. The second was a leak simulation test also conducted immediately after the original test. The third type was a complete retest conducted on a different day and generally by a different crew. Each of these types estimates a different source of variation possible in the tank tests. A tabulation of all of the retests appears as Table D-1. (Note that a negative volume change is a leak, while a positive volume change represents net inflow. In the body of the report, leaks are reported without minus signs.) The simulated leak retests are tabulated in Table D-2. A table summarizing the estimates of bias (accuracy) and standard deviation (precision) based on each type of test is presented as Table D-3. It should be noted that the three types of retests estimate different sources of variation and so are not directly comparable to each other.

A. Leak Simulations

The leak simulation tests were conducted after the original test was concluded. Generally they were only conducted when the original test indicated that the tank was tight or had a small estimated volume change. The volume rate used for leak simulation was on the order of 0.1 gallons per hour, so a large volume change would overwhelm it.

The purpose of the leak simulation tests was to document that the testing method could detect leaks of known size in tanks that appeared to be tight. In addition, use of the leak

Table D-1. Retest Data Summary

Survey ID	Volume	Fueltype	Type	Initial Date	QC Date	Initial Rate	SE	Retest Rate	SE
N02784A	2007	DIESEL	BTB	0730	0731	-.015	.007	-.009	.005
N131078A	3985	UNLEADED	BTB	0822	0822	-.102	.018	-.079	.013
N171261A	3979	GASOHOL	BTB	0804	0804	.049	.019	.040	.010
N21581B	3973	PRE UNLD	BTB	0731	0801	-.822	.038	-1.315	.059
N281389B	11988	REGULAR	BTB	0806	0807	-.025	.019	-.032	.020
L01034A	1039	UNLEADED	RT	0709	0812	.013	.014	-.005	.009
L01036B	2005	DIESEL	RT	0712	0826	-.055	.049	-.009	.008
L01037A	4013	SUP UNLD	RT	0724	0828	.019	.013	-.028	.022
L01037B	4013	REGULAR	RT	0724	0828	.036	.016	.017	.012
L02068A	3989	REGULAR	RT	0809	0810	.039	.014	-.019	.012
G03018A	3010	DIESEL #1	RT	0731	0827	-.194	.01	-.226	.005
G03018B	3010	REGULAR	RT	0731	0827	.060	.009	-.005	.009
L03095A	6049	DIESEL	RT	0802	0826	-.036	.011	-.117	.006
L03095B	6048	DIESEL	RT	0802	0826	-.032	.013	-.047	.007
G06013A	6018	REGULAR	RT	0724	0828	-.153	.018	-.097	.016
G06013B	6018	DIESEL	RT	0724	0828	-.089	.011	-.325	.017
G06028A	2964	REGULAR	RT	0721	0829	.053	.016	.049	.008
G06028B	2964	DIESEL	RT	0721	0829	-.708	.018	-.613	.015
G07010A	277	DIESEL	RT	0628	0826	-.007	.054	-.001	.009
G07010B	566	REGULAR	RT	0628	0826	-.005	.027	-.017	.012
G10020T1	10155	REGULAR	RT	0625	0816	1.189	.322	.175	.022
G10020T2	10155	UNLEADED	RT	0626	0816	.584	.028	.109	.018
N141107A	1035	GASOHOL	RT	0817	0831	.006	.007	-.013	.010
N141107B	1033	DIESEL	RT	0817	0831	-.327	.010	-.377	.027
N151141A	10576	DIESEL	RT	0817	0824	-.621	.023	-.411	.015
N151141C	21154	DIESEL #1	RT	0817	0824	-.129	.008	-.009	.008
G16005AR	1003	UNLEADED	RT	0722	0828	-.006	.021	.025	.011
G16005BR	295	REGULAR	RT	0722	0828	.046	.015	.022	.011
L16394A	1023	REGULAR	RT	0728	0831	-.021	.012	-.030	.008
L16394B	1039	UNLEADED	RT	0728	0831	.018	.012	.011	.014
N171261G	576	DIESEL	RT	0804	0810	-.014	.007	-.010	.004
N181323C	1005	UNLEADED	RT	0721	0825	.025	.04	-.013	.008
N181323D	1005	REGULAR	RT	0721	0825	.034	.013	-.015	.008
N181326B	1033	UNLEADED	RT	0722	0829	-.076	.018	-.032	.007
G19068A	1005	REGULAR	RT	0715	0828	-.614	.014	-.559	.018
G19068B	4032	DIESEL	RT	0715	0828	.070	.008	-.002	.011
G19068C	1038	UNLEADED	RT	0715	0828	-.068	.014	-.076	.011
G19101A	566	DIESEL	RT	0712	0827	-.078	.02	-.100	.008
N19525A1	8060	UNLEADED	RT	0710	0822	.032	.05	.044	.030
N34128A	6262	SUP UNLD	RT	0617	0828	-.034	.009	.044	.003
N34128B	8000	UNLEADED	RT	0615	0828	-.080	.03	-.053	.014

Table D-2. Simulated Leak Summary

Survey ID	Test Date	Volume	Fuel Type	Bckgrd LR	SE	Obsrvd LR	SE	Simltd LR	Diff= Obs-Back	Sim-Diff
L01036A	0712	10154	UNLEADED	0.002	0.055	-.095	0.011	-.101	-.097	-.004
L05131B	0718	5955	REGULAR	-.082	0.200	-.055	0.012	-.049	0.027	-.076
N141107BL	0831	1036	DIESEL	-.377	0.027	-.200	0.008	-.059	0.177	-.236
N161191B	0731	10575	AV JET	-.485	0.010	-1.455	0.030	-.875	-.970	0.095
N181317A	0806	565	REGULAR	0.021	0.031	-.067	0.017	-.048	-.088	0.040
N181317A1	0806	565	REGULAR	0.021	0.031	-.084	0.019	-.113	-.105	-.008
N181326B	0829	1033	UNLEADED	-.032	0.007	-.184	0.006	-.154	-.152	-.002
G19068A	0828	4033	DIESEL	-.002	0.011	-.044	0.007	-.037	-.042	0.005
G19101A	0827	566	DIESEL	-.100	0.008	-.096	0.003	-.056	0.004	-.060
N19525A1	0710	4032	UNLEADED	0.032	0.050	-.079	0.020	-.059	-.111	0.052
N261347A	0820	10146	DIESEL	-.005	0.025	-.016	0.033	-.051	-.011	-.040
F271172A	0813	1037	REGULAR	0.019	0.012	-.070	0.019	-.090	-.089	-.001
N271375B	0817	1039	UNLEADED	0.017	0.010	-.094	0.012	-.115	-.111	-.004

Table D-3. Retest results

Type	Mean difference (gallons per hour)	N	Variance $(gph)^2$	Mean squared error $(gph)^2$	Standard deviation (gph)	Root mean squared error (gph)
Leak simulation	-0.00891	11	0.00066(1)	0.00074	0.0257(1)	0.0272
Back to back	0.00629	14	0.00053(1)	0.00057	0.0231(1)	0.0239
Retests	0.00297	34	0.00254(2)	0.00255	0.0504(2)	0.0505

(1) For the leak simulation and back to back retests, the variance of the simulated minus the differenced observed rates and the initial minus the retest rates is an estimate of twice the underlying within-test variance plus any variance due to testing at successive 2 hour periods. The corresponding estimated variance is reported here.

(2) For complete retests, the variance of the initial rates minus the retest rates estimates twice the total variance (within- and between-tests). The corresponding estimated total variance is estimated here.

simulation allows for an estimate of the accuracy of the test as well as its precision. The accuracy refers to the ability of the test to measure a known volume change, while the precision of the test refers to its ability to reproduce measured rates.

Thirteen leak simulation tests were conducted. Two of these were conducted on tanks that had estimated volume rates that indicated that the tanks were probably leaking. These tests were excluded from the analysis because variability is known to increase for leaking tanks. The results from all of the leak simulation tests are tabulated in Table D-2. Using the leak simulation results from the tanks with small estimated volume changes (less than 0.1 gallons per hour in absolute value) gave the following results.

Three rates were calculated from leak simulations. The first was a baseline rate for the tank. This was estimated during the regular tank test. While the leak simulation was conducted, a measured rate was estimated. This is the rate observed by the testing method during leak simulation. It is presumed to be composed of the tank rate plus the simulated rate. The simulated rate is calculated by collecting product drawn from the tank at a constant rate, weighing it on a triple beam balance, and converting the weight to volume at the temperature of the product in the tank. The difference between the observed rate during the simulation and the baseline rate provides an estimate of the simulated rate. The difference between this and the actual simulated rate can be used to assess the accuracy of the test.

The average difference between the measured rate and the simulated rate was -0.00891 gallons per hour, based on the 11 leak simulations where the tank was not estimated to be leaking. If the other two simulations are included, this mean difference increases to -0.0184 gallons per hour. The difference between the measured rate and the simulated rate is interpreted as an estimate of bias. The variance of the differences about their mean provides an estimate of twice the within-test precision plus any variance due to taking successive 2 hour test periods. Taking half the variance of differences estimates the variance itself. The estimate was 0.00066 gallons per hour squared for the 11 tests. (It was larger, 0.00291 gallons per hour, if all 13 tests were used.) A mean squared error (MSE) can be calculated to incorporate both types of error--accuracy and precision. The mean squared error is the sum of the bias squared plus the within-test variance. In this case it was 0.00o74 gallons per hour squared (or 0.00325 gallons per hour squared for all 13 tests).

The bias is clearly not significant, in that it does not differ significantly from zero (t = -0.347, 10 degrees of freedom). As a result, the variance and the mean squared error are nearly identical. A measure of variation often used is the standard deviation (or root mean squared error if bias is present), which is the square root of the variance (or MSE). This measure has the advantage that its units are the same as the measurement, gallons per hour. The standard deviation was estimated to be 0.0257 gallons per hour for these data.

B. Back to Back Retests

Back to back retests were conducted on a total of 18 tanks, which includes the 13 tanks with leak simulations. Five tanks had back to back retests without leak simulation. The purpose of the back to back retests was to estimate the stability of the test method. That is, to ensure that the volume change estimate did not differ markedly if based on the succeeding 2 hours after the test.

As with all of these tests, variability is expected to be larger if the initial leak rate or volume change is larger. For this reason, the results of the back to back retests are presented primarily for those tests with volume change rates less than 0.1 gallons per hour in absolute value. Retest results for tanks with larger volume rates were more variable but generally consistent.

The average difference between the original and retest for the 14 tests with small volume changes was 0.00629 gallons per hour. The estimate of within-test plus change over 2 hour periods variance was 0.00053 gallons per hour squared, giving a mean squared error of 0.00057 gallons per hour squared. The corresponding standard deviation was 0.0231 gallons per hour and the root mean squared error estimate was 0.0239 gallons per hour. The mean difference was not significantly different from zero (t = 0.272, 13 df).

If all 18 back to back retests are used, the estimates are slightly larger. The mean difference was -0.0134 gallons per hour, with the variance and MSE being 0.00893 and 0.00910 gallons per hour squared, respectively. The mean difference did not differ significantly from zero (t = -0.14, 17 df).

C. Complete Retests

The complete retests consist of revisits to the site on a different day. Typically this includes a different crew and involves rescheduling and refilling the tank. The complete retests incorporate all of the features of a tank test and so include all the sources of error including potential difference from crew to crew and differences due to weather conditions, nearby traffic flow, day of the week, etc. In addition, there is a possibility that the tank is different at the time of the retest. In fact, two of the retests originally scheduled were cancelled when it was found that the tanks had been repaired between the initial test and the scheduled retest. In addition, two retests were performed and it was then discovered that the tanks had been repaired between the initial test and retest. These data are also not included, as they would measure an additional source of variation which is not of interest, i.e., repair. Two other retests were performed on tanks that were initially determined to have large vapor pockets. These two tanks were retested later and on retesting were again found to have large vapor pockets. The results of the test and retest for these tanks with vapor problems agreed qualitatively; however, the numerical agreement was not close. The reason for this may be that the vapor pocket trapped in the tank was of different size. There were also different ambient conditions that would affect the vapor differently. For these reasons, the vapor retests were not included in the estimate of the variance from the retests.

The mean difference from the subset of 34 good complete retests was 0.00297 gallons per hour. For complete retests, the variance of the differences between initial and retest rates estimates twice the total variance; that is, the within-test plus between-test components. We report here the corresponding estimated total variance. The estimated total variance was 0.00254 gallons per hour squared, giving a mean squared error of 0.00255 gallons per hour squared. If attention is restricted to initial tests with estimated volume change rates of less than 0.2 gallons per hour in absolute value, the results change slightly. For this set of 30 retests, the mean difference was 0.0137 gallons per hour, while the variance was 0.00181 gallons per hour squared. This resulted in a mean squared error of 0.00200 gallons per hour squared. Neither mean difference is significantly different from zero (t = 0.059, 33 df, t = 0.322, 29 df, respectively). The cases with larger volume change rates were somewhat more variable, however.

As noted above, there were two retests of tanks that had vapor problems. The initial test results showed volume increases of 1.189 gallons per hour and 0.584 gallons per hour, respectively, based on very short test times. The retests based on longer times gave volume increases of 0.175 gallons per hour and 0.109 gallons per hour, respectively, with again the conclusion of a trapped vapor pocket. Both of these retests agreed on the presence of vapor. The difference in apparent volume increase rates may be due to a number of factors. The initial test was terminated quite early. The early termination may have led to variable results. The size of the vapor pocket may have differed between the initial and retest. The changes in conditions--temperature, barometric pressure--that affect the vapor pocket may have differed. All of these could lead to the observed differences in apparent volume increase rates. However, the consistency of the test and retest in identifying the tank as having a problem with trapped vapor suggest that the test method is consistent in identifying problem tanks.

There were two tanks that were retested after the tank was repaired. One of these had an initial leak rate estimated to be -0.057 gallons per hour with a standard error of 0.004 gallons per hour. The rate estimated on the retest was -0.017 gallons per with a standard error of 0.0094 gallons per hour. Although the tank was considered to be leaking by the NFPA Standard 329 and the owner took corrective action, the volume change rate estimated initially was fairly small. The second tank had an initial leak rate estimated as -0.137 gallons per hour with a standard error of 0.009 gallons per hour. On the retest, the estimated volume change was -0.132 gallons per hour with a standard error of 0.007 gallons per hour. Little change was observed. However, on the retest, the testing company certified the tank as tight based on the last hour of data, where they estimated a rate of -0.044 gallons per hour. The data from this test showed little difference from the initial test. Except for the known fact that some repairs were done to the tank, there would be no reason to exclude it from the retest data. Even the former retest would not be viewed as suspect from the change in estimated leak rates.

The retest data analysis showed no evidence of bias in the test methods. Both the back to back retest and the leak simulations estimated within-test (plus variation from one 2 hour period to the next) standard deviations on the order of 0.025 gallons per hour. The complete retest data gave a total standard deviation estimate of 0.05 gallons per hour.

V. ESTIMATION OF TOTAL VARIANCE

The various types of retests offered not only a means of estimating both within- and between-test variation, but also evidence that the between-test variation is sizeable compared to the observed variance of a single test result. In order to use a statistical hypothesis testing approach to determine whether the observed leak rate in a given test is evidence of a leak rather than due to measurement fluctuation, the total variance must be estimated for each test. This was done by estimating the between-test variation from all the data taken together and adding this to the estimate of within-test variance generated by the data from each test. The within-test standard error was squared, the overall between-test variance added, and the square root of the sum was taken as the estimate of total standard error used in the leak status decision process.

Two sources of information were used to estimate the between-test variance. The two sources agreed fairly well, which served as a validity check on the results. The two estimates were then averaged (using relative weights based on the number of cases each estimate was based on) to form the needed estimate of between-test variance. Table D-4 summarizes this process.

The complete retests provided one data base from which to estimate between-test variance. For a retested tank i, let k index the test (1 or 2) and j index the 5-minute volume change measurement for a given test. Then a given 5-minute volume change measurement, x_{ikj}, can be written:

$$x_{ikj} = L_i + d_{ik} + e_{ikj} \qquad \text{[Equation D-1]}$$

where

L_i = tank i's true leak rate under test conditions;

d_{ik} = random measurement error of L_i due to differences from one test occasion to another; and

e_{ikj} = random measurement error of the individual 5-minute volume change measurement for this test.

Since the various quality assurance double-testing methods showed no evidence of bias, it is reasonable to assume that

$$E(e_{ikj}) = 0$$
$$E(d_{ik}) = 0.$$

Table D-4. Estimates of between-test variance (based on observed volume change rates not adjusted for test pressure)

Data Base	N	Estimated total variance (gph)	Estimated within-test variance $(gph)^2$	Estimated between-test variance $(gph)^2$	Estimated total standard error (gph)
Complete retest	34	0.00254	0.00033	0.00222	0.0504
Tank tests with measured volume change between 0.0 and 0.2 gph	133	0.00267	0.00073	0.00193	0.0517
Combined estimate	167	0.00264	0.00065	0.00199	0.0514

We also assume that

$$E(d_{i1}d_{i2}) = 0,$$
$$E(\bar{e}_{i1}\bar{e}_{i2}) = 0,$$
$$E(d_{ik}\bar{e}_{ik}) = 0,$$

and that the d_{ik} and e_{ikj} each have a constant variance, denoted as

$$\sigma_b^2 = \text{between-test variance} = E(d_{ik}{}^2)$$

and

$$\sigma_w^2 = \text{within-test variance} = E(\bar{e}_{ik}{}^2),$$

where the mean of the e_{ikj} is taken over all measurements for the k-th test of the i-th tank, usually 24.

Starting with Equation D-1, an estimate of total variance can be based on the two estimated leak rates, $\bar{x}_{i1}$ (the initial rate) and $\bar{x}_{i2}$ (the retest rate) as follows:

$$E(\bar{x}_{i1} - \bar{x}_{i2})^2$$
$$= E(d_{i1} + \bar{e}_{i1} - d_{i2} - \bar{e}_{i2})^2$$
$$= E(d_{i1} - d_{i2})^2 + E(\bar{e}_{i1} - \bar{e}_{i2})^2$$

because the d_{ik} and e_{ikj} are independent. This, in turn, equals:

$$2\sigma_b^2 + 2\sigma_w^2.$$

Thus

$$E((1/2)(1/n)\sum_{i=1}^{n}(\bar{x}_{i1} - \bar{x}_{i2})^2) = \sigma_b^2 + \sigma_w^2.$$

and

$$E((1/((2)\cdot(n)))\sum_{i=1}^{n}\sum_{k=1}^{2}s_{ik}^2) = \sigma_w^2$$

where

$$s_{ik}^2 = 1/(n_i(n_i-1))\sum_{i=1}^{n_i}(\bar{x}_{ik} - x_{ikj})^2.$$

Therefore, letting

$$s_{b,\text{retest}}^2 = (1/2)(1/n)\left\{\sum_{i=1}^{n}(\bar{x}_{i1} - \bar{x}_{i2})^2 - \sum_{i=1}^{n}\sum_{k=1}^{2}s_{ik}^2\right\} \qquad \text{[Equation D-2]}$$

we have

$$E(s_{b,\text{retest}}^2) = \sigma_b^2.$$

The 34 retest leak rates and their within-test standard errors were used in Equation D-2 to compute an estimate of σ_b^2 based on the retest results.

Tests on tanks which can be assumed not to be leaking provide a second estimate of σ^2. Here, the true leak rate is zero, and we have

$$x_{ij} = d_i + e_{ij} \qquad \text{[Equation D-3]}$$

with assumptions on d_i and e_{ij} as stated above. (We suppress k since only one test was done on these tanks.) In this case we have

$$E(\bar{x}_i{}^2) = \sigma_b^2 + \sigma_w^2$$

and

$$S^2_{b,\text{tight tanks}} = 1/n\left\{\sum_{i=1}^{n} \bar{x}_i^2 - \sum_{i=1}^{n} s_i^2\right\}. \qquad \text{[Equation D-4]}$$

Clearly

$$E(S^2_{b,\text{tight tanks}}) = \sigma_b^2.$$

Defining tanks which can be assumed not to be leaking requires some decision-making. By limiting this group to tanks with measured average volume change between 0.0 and 0.2 gallons per hour, the tanks which may be leaking (negative measured volume change) are eliminated as are the test results which are likely due to vapor pockets (high positive measured inflow).

The results of applying Equation D-3 to the 34 retests and Equation D-4 to the 133 measured volume changes between 0.0 and 0.2 gallons per hour are shown in Table D-4. It can be seen that the two approaches yield similar estimates and in particular indicate the importance of the between-test component of the total variation in $\bar{x}_i$. It should be noted that these figures are all as measured, and not as adjusted for test pressure. The adjustment deflates the measured leak rate by about half (the factors range from 0.395 to .608), but is applicable only to actual leaks, since it adjusts the rate from test pressure to an assumed operating pressure.

To get one estimate of between-test variance to use in adjusting within-test standard error up to total standard error, the two estimates described above were averaged with relative weights based on the number of cases each was based on:

$$34/167\ (0.00222) + 133/167\ (0.00193) = 0.00199$$

Thus, to estimate the total standard error for a given observed leak rate, 0.00199 was added to the reported (within-test) standard error squared, and the square root taken. This total standard error was used in the statistical hypothesis test method for determining leak status described in Section 8 of this report.

VI. DETERMINATION OF LEAK STATUS

The physical tightness test for each tank system provided an unbiased estimate of volume change rate and an estimate of the within-test variability of that rate. The complete retest data provided an estimate of the between-test variability of the measured rates. However, the test itself did not provide a definitive leak status determination, that is, an unequivocal "yes" or "no" to the questions "Is this tank tight?" or "Is this tank leaking?" In order to estimate the number of tanks in the country that are leaking and to look at the subset of leaking tanks to investigate factors associated with leaking, such a determination must be made (or the test result ruled inconclusive) for each tested tank system. Two approaches were considered for making this determination: a cut-off rule, comparing the observed volume change rate to a pre-determined cut-off; or declaring a system leaking or not by a hypothesis testing approach. The latter approach was chosen for the study determination of leak status. Two drawbacks of the cut-off approach were that there was no scientific basis for establishing a specific level for the cut-off at the time of the survey, and that it did not take into account the differences in precision achieved by the individual tests.

The null hypothesis to be tested in determining leak status is:

$$H_o : L_i = 0$$

where L_i is the true leak rate of the tank. The alternative is

$$H_A : L_i > 0.$$

As shown in Part V, above, we model the test result, $\bar{x}_i$, as having a total variance composed of a within-test and between-test component. This total variance is estimated as

$$s_t^2 = s_{wi}^2 + s_b^2$$

where the first term is the within-test variance measured from the i-th tank test data and the second term was estimated as described above (Part V). The test statistic is therefore

$$z = \bar{x}_i/s_t$$

and is compared to one-tailed tables of the Normal distribution to determine whether H_o can be rejected at a certain level of significance. If H_o is rejected, we say the tank system is judged to be leaking.

Several significance levels were examined, as was the trade-off between significance and power. The power was estimated for a specific leak rate after adjusting the leak rates and their associated standard errors for test pressure (see Part VII, below, for this adjustment procedure). A significance level of $\alpha = 0.05$ was used for the survey determination of leak status.

VII. ADJUSTMENT OF TEST LEAK RATES

The Petro-Tite test places increased hydrostatic pressure on the tank system for the test. As a consequence of this, any leak or flow through an orifice in the tank will be increased over what would occur under the (smaller) pressure encountered in operation. Similarly, the line test places a higher pressure on the delivery line and so the leak rates estimated under the test will be higher than what would occur in operation.

For systems, tanks, or lines that are determined to be leaking, it is useful to adjust the leak rates estimated under the test conditions to a standard set of operating conditions. It should be noted that the basis for the adjustment is the assumption that the leak is a flow of a liquid through an orifice or hole. Such flows are more rapid under higher pressure than under low pressure. However, if there is no orifice, no flow would occur under high or low pressure. Thus, it is not logically consistent to adjust test volume change rates for pressure in the event that the system was judged to be tight.

The adjustments are based on Bernoulli's law. More specifically, adjustments are based on Torricelli's form of the Bernoulli equation. In order for the adjustments to be reasonable, the assumptions for these physical laws must hold. It should be noted that the assumptions for Torricelli's and Bernoulli's law assume that the flow is through an orifice with neither resistance nor turbulence. In practice, this is not the case. While the flow rate will be generally small enough so that the assumption of a turbulence is reasonable, and so that the head change is slow enough to be neglected, in most cases, leaks will probably be through corroded sections and will be into soil which may present some resistance. The effect of resistance would be to lower the flow rate. However, how much the flow rate would be lowered under the different pressures is not known. Consequently, the effect of violation of these assumptions on the adjustment to the leak rates is not known. It is assumed to be negligible. There are some other, implicit assumptions. These include that the orifice is constant, that the temperature and density do not change, and that the product is not viscous.

Torricelli's form of Bernoulli's law can be used to calculate adjustments to the flow rates. In order to do this, several assumptions must be made. The set of assumptions used in these calculations is detailed below. A step by step procedure for the adjustments is given first. These are the adjustments to be made in the ideal situation where the tank system leak was quantifiable and a valid line test with quantifiable leak rate was done. In our data base, among tank systems judged to be leaking with quantifiable leak rates, only 39 percent had valid line test leak rates. Since the majority of cases had no valid line data and the separate analysis described in Section 8 of the report showed that line leaks accounted for a very small proportion of system leaks when they were done, leak status and leak rate as reported in the Major Findings are based on measured tank system leak rates adjusted directly to operating conditions, without adjusting for line test results. We present the line test adjustment procedure since it was used for the analysis in Part V of Section 8 and for future use in analyzing data collected in the national survey.

A. Adjusting the Line Leak Rate to the System Leak Rate

Since the line test is conducted at higher pressure than the system test, the leak rates estimated from the line test are not directly comparable to those estimated from the system test. This adjustment accounts for the difference in pressure and adjusts the line test rates to be comparable with the system test rates. These adjustments are calculated differently for pressure systems and suction systems and for gasoline and diesel fuels.

The assumptions made for this adjustment are the following. These are in addition to the assumptions needed for the use of Bernoulli's equation to adjust the flow rates.

- The orifice where the leak (if any) occurs is where the line joins the top of the tank.
- The tank is assumed to be buried to a depth of 3 feet to the top of the tank.
- The water table is assumed below the bottom of the tank.
- Three tank diameters are assumed: 48 inches, 64 inches, and 96 inches.

Table D-5 gives the adjustment factors to adjust the rates estimated from the line test to the conditions assumed for the system test. The factors as presented are multiplicative. To convert a rate estimated from the line test to the equivalent system rate, multiply the estimated line rate by the factor in the table.

The difference by type of delivery system results from the fact that the line test is conducted at 15 PSIG for suction lines and at 50 PSIG for pressure lines.

B. Subtracting Line Rates From System Rates When Valid Line Results are Present

After adjusting the line test results by the factors in Table D-5, the line test rates would be comparable to the system test results. The line test rates could be subtracted to obtain an approximate tank rate. This is the rate for the tank system excluding delivery lines, but still including any other plumbing such as fill pipes, vent pipes, etc.

If a system has more than one delivery line, each line test rate would be adjusted, then all line test rates subtracted from the system rate. For the tank systems for which the line was found to be untestable, the line rate cannot be separated from the system rate.

Table D-5. Adjustment factors for line test rates

Tank diameter	Suction	Pressure
48 inches (0 - 1,000 gallons)	0.431	0.236
64 inches (1,101 - 7,000 gallons)	0.395	0.216
96 inches (7,001 - 15,000 gallons)	0.317	0.174

C. Adjusting the Tank Rate (or System Rate) to Assumed Operating Rate

Since the test is conducted at elevated pressure, flow rates through any orifices will be larger under the test conditions than they would be under actual tank operation. The magnitude of the difference depends on a large number of variables. In particular, flow rates would vary by location of the hole in the tank (distance from the bottom), amount of fuel in the tank, and pressure of a water table part way up on the tank. The adjustment factors would also vary with diameter of the tank. Since diesel tanks were tested at the same pressure (hence at a lower head-distance) as gasoline tanks, the adjustment also varies with fuel type because of the density difference.

The standard assumptions for calculating the adjustment factors presented in Table D-6 are as follows. These are in addition to the basic assumptions of Bernoulli's law.

- The water table is assumed to be below the bottom of the tank.
- The tank is assumed to be buried to the depth of 3 feet from grade to top of tank.
- Three tank diameters are assumed (48, 64, and 96 inches).
- The average operating level of the tank is assumed to be half full.
- The orifice or hole is assumed to be in the bottom of the tank.

Table D-6 then gives adjustment factors to adjust the estimated tank system leak rate to the assumed standard set of operating conditions. The factors should be multiplied by the leak rate estimated under the system test to obtain the adjusted

Table D-6. Adjustment factors for tank (system) rates*

Tank diameter	Adjustment factor	
	Gasoline	Diesel
48 inches (0 - 1,000 gallons)	0.395	0.430
64 inches (1,101 - 7,000 gallons)	0.456	0.496
96 inches (7,001 - 15,000 gallons)	0.558	0.608

*If a standard height had been used for both fuels, the gasoline column would apply to both.

leak rate. Note that this adjustment can be done to the system test leak rate, or to the leak rate remaining after any relevant line leak rates have been adjusted to test conditions and subtracted off.

Multiplying the rates estimated under the system test by the adjustment factors given in Table D-6 will give adjusted rates for the assumed standard set of operating conditions described in the assumptions above.

APPENDIX E

INVENTORY RECONCILIATION METHODS

I. EPA INVENTORY RECONCILIATION METHOD

EPA has developed a simple method[1] for monitoring underground motor fuel storage tank inventory records to detect a systematic deficit which may be attributable to a leak. The method is based on counts of the number of daily underages found in the inventory record and is simple enough to be implemented by a tank operator without excessive calculation or burdensome record-keeping. As originally formulated, the method is intended for application as the "first line of defense against leaks" in an on-going monitoring program. Thus, the approach is sequential in nature and involves making a decision on the presence or absence of an inventory deficit at the end of each 30-business-day period, based on a comparison between the cumulative count of daily underages and certain statistically-derived "action numbers"[1]. A cumulative number of underages in excess of the appropriate action number was to be interpreted as evidence of a deficit. The statistical model and calculations underlying the method were detailed in the report from Battelle Columbus Laboratories to EPA[2]. The basic method required modification for application to the inventory data collected in the survey because each sampled facility provided only a single, one-time record of

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[1] U.S. EPA, Office of Toxic Substances, "More About Leaking Underground Storage Tanks: A Background Booklet for the Chemical Advisory," (October 1984).

[2] David C. Cox, "Performance of the Chemical Advisory Inventory Analysis Method Under Various Scenarios," Report from Battelle Columbus Laboratories to EPA under contract No. 68-01-6721 (April 1984).

30 days' inventory for analysis. The purpose of this section is to describe the statistical model on which the modified EPA method is based.

The decision rule for the proposed method will be defined by considering a well-run station where the only sources of discrepancy in the inventory records are (i) a daily leak of magnitude L and (ii) unavoidable random error in the daily stick measurement of the tank. Successive daily errors are assumed independent and identically normally distributed with mean zero; this assumption is supported by the research of Warren Rogers[3,4]. Hence, we can write:

$$X_i = x_i + e_i$$

where X_i is the i^{th} daily stick measurement, x_i is the true quantity of gasoline in the tank at the close of the i^{th} day, and $e_i \sim N(0, \sigma^2)$ is the stick measurement error. Now consider a period of n days, assuming for simplicity that the station is open every day. The process of balancing inventory at the end of each day, as described in the literature[5] and assuming that there is no metering error at the pump[6], leads to a set of daily variances (discrepancies),

$$d_i = -L + e_i - e_{i-1}, \ i = 1, \ldots n.$$

---

[3] "Inventory Reconciliation system," Warren Rogers Associates.

[4] Warren Rogers, personal communication.

[5] American Petroleum Institute: "Recording Practices for Bulk Liquid Stock Control at Retail Outlets," (1977).

[6] Metering error, if present, can be estimated and removed from the record, see American Petroleum Institute, "Recommended Practice for Bulk Liquid Stock Control at Retail Outlets," (1977).

Let N be the total number of negative daily variances,

$$N = \#\{i \mid 1 \leq i \leq n,\ d_i < 0\}.$$

Clearly, large values of N suggest that there is a leak, i.e., $L > 0$. The exact probability distribution of N is, in general, very difficult to derive. However, of the special case of no leak, i.e., $L = 0$, the calculation has been carried out[7]. Table E-1 shows the distribution for the case $n = 30$ of most interest. In general, we must rely on a normal approximation to the distribution. This is derived as follows. We first find the mean E(N) and variance V(N) as follows. Define:

$$p = \Pr(d_i < 0)$$

$$p_1 = \Pr(d_i < 0,\ d_{i+1} < 0)$$

$$I_i = \begin{cases} 1\ , & \text{if } d_i < 0 \\ 0\ , & \text{else} \end{cases}$$

Then $E(I_i) = p$, $E(I_iI_j) = p^2$ if $|j-i| > 1$ (because then I_i, I_j are independent), $E(I_iI_{i+1}) = p_1$. Thus

$$E(N) = E(\sum_{i=1}^{n} I_i) = np. \text{ Also,}$$

$$\begin{aligned} E(N^2) &= E(\sum_{i=1}^{n} I_i^2 + 2\sum_{i<j} I_iI_j) \\ &= E(\sum_{i=1}^{n} I_i^2 + 2\sum_{i=1}^{n-1} I_iI_{i+1} + 2\sum_{i<j-1} I_iI_j) \\ &= np + 2(n-1)p_1 + [n(n-1) - 2\ (n-1)]p^2 \end{aligned}$$

Therefore

$$\begin{aligned} V(N) &= E(N^2) - (E(N))^2 \\ &= np(1-p) - 2(n-1)(p^2 - p_1) \\ &\equiv \sigma(L)^2 \end{aligned} \qquad [1]$$

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[7] Warren Rogers, "The Exact Null Distribution of the Number of Negative Daily Variances," Report from Warren Rogers Associates to EPA, (September 1984).

Table E-1. Probability distribution of the number of negative daily variances, N, for the no-leak case, based on 30-day inventory

No. of negative variances	Probability of occurrence
≤ 10	0.0024
11	0.0121
12	0.0456
13	0.1161
14	0.2022
15	0.2432
16	0.2022
17	0.1161
18	0.0456
19	0.0121
≥ 20	0.0024

We approximate N by a normal distribution with mean np +0.5 and variance $\sigma(L)^2$. The mean is taken as np +0.5 to provide an approximate continuity correction for use in the upper tail of the distribution, in which our greatest interest lies.

To check the accuracy of the approximation, consider the case L = O. Then,

$$
\begin{aligned}
p_i &= P_r(_i < o,\ d_i + 1 < o) = P_r(e_i < e_{i-1},\ e_{i+1} < e_i) \\
&= P_r(e_{i + 1} < e_i < e_{i-1}) \\
&= 1/6
\end{aligned}
$$

since all six orderings of e_{i-1}, e_i, $e_{i + 1}$ are equally likely. Thus, from Equation [1],

$$\sigma(L)^2 = n/4 - 2(n-1)/12 = (n+2)/12$$

Setting n = 30 we have the approximation,

$$N \sim N(15.5,\ 2.67)$$

Table E-2. shows the accuracy of the approximation.

Table E-2. Accuracy of normal approximation to distribution of N for the case L = O (no leak)

n	$P_r(N \geq n)$ (exact)	$P_r(N \geq n)$ (approximate)
15	0.6216	0.6217
16	0.3784	0.3783
17	0.1762	0.1788
18	0.0601	0.0630
19	0.0145	0.0162
20	0.0024	0.0029

Clearly the approximation is sufficiently accurate over the range of n reported. For $L \neq 0$, the exact distribution of N has not been derived. We will rely on the normal approximation in such cases. The mean and standard deviation of the approximating distribution have been calculated and are shown in Table E-3.

Table E-3. Mean and standard deviation of normal approximation to the distribution of N, the number of negative daily variances, for various values of the daily leak rate L, for a 30-day inventory

L (gallons)	Mean	Standard deviation
2	16.46	1.636
3	16.93	1.641
4	17.41	1.647
5	17.88	1.654
6	18.34	1.665
7	18.81	1.678
8	19.27	1.684
9	19.72	1.699
10	20.16	1.707

The final feature for which we must account before we can determine the decision rule is round-off error. In practice, inventory values are typically reported to the nearest gallon so that an exact inventory balance, i.e., a zero variance, can occur due to round-off. This is fairly common in actual inventory data. We will assume that a zero variance is reported if the actual variance is less than 0.5 gallons in absolute value. Thus, a negative variance is reported only if the actual variance is less than -0.5 gallons. Let N* be the number of negative variances actually reported and assume $\sigma\sqrt{2} = 25$ gallons. Then the distribution of N* should be approximated by a normal distribution with mean and standard deviation shown in Table E-4.

Table E-4. Mean and standard deviation of normal approximation to the distribution of N*, the number of negative daily variances accounting for round-off error, for various values of the leak rate L, for a 30-day inventory

L (gallons)	Mean	Standard deviation
0	15.26	1.633
1	15.74	1.634
2	16.22	1.635
3	16.69	1.638
4	17.17	1.644
5	17.64	1.650
6	18.11	1.660
7	18.58	1.672
8	19.04	1.681
9	19.49	1.687
10	19.94	1.703

Now suppose we have 30 days' inventory and there is no leak. Using the approximating distribution from Table E-4 the number of daily variances observed should have the distribution shown in Table E-5.

Table E-5. Probability distribution of the number of negative daily variances, N*, observed when no leak is present

n = number of negative variances	($P_r(N^* \geq n)$
15	0.564
16	0.326
17	0.142
18	0.047
19	0.011
20	0.002

Thus, if we make 18 or more negatives our criterion for deciding that a deficit is present, there is approximately a five percent false-positive rate. That is, a tank with no leak and no source of error in inventory other than random measurement error due to sticking has approximately a five percent chance of being erroneously classified as a leaker. Note that false-positives due to other factors such as theft are not accounted for here. The detection capability of this version of the EPA inventory analysis method can now be calculated using the values given in Table E-4. Results are shown in Table E-6.

Table E-6. Probability of detection of leaks of various sizes using the modified EPA inventory method based on 30 days' data

Actual leak		Detection probability
Gallons/day	Gallons/hour	
1	.04	0.08
2	.08	0.14
3	.12	0.21
4	.17	0.31
5	.21	0.41
6	.25	0.53
7	.29	0.64
8	.33	0.73
9	.37	0.81
10	.42	0.87

Thus, leaks of at least nine gallons per day or more have better than 80 percent chance of detection. It should be noted that the detection capability of the simple inventory method based on only 30 days' data would be expected to be poor. The method was designed, as explained previously, for use as a tool for on-going monitoring programs.

II. WARREN ROGERS ASSOCIATES' INVENTORY RECONCILIATION METHOD

Warren Rogers Associates (WRA) has developed a computerized system for analyzing daily inventory data from underground storage tanks in order to identify leaks[8]. The details of the method are proprietary. This section provides a brief description of publicly-available information on the model and should not be interpreted as an evaluation or endorsement by EPA.

The WRA system was developed in response to the perceived inadequacy of conventional, routine inventory accounting in detecting small or moderate leaks. Typically, such leaks are masked in the data by a variety of errors. For example, a single delivery error of 300 gallons could mask a 10 gallon-per-day leak based on 30 days' inventory. The purpose of the model is to isolate, identify, and quantify these errors.

Errors accounted for include:

- Delivery errors;
- Unexplained additions;
- Pump meter error;
- Temperature effects;
- Stick error; and
- Tank or line leaks.

Occasionally, other, rarer, errors will appear, e.g., use of an incorrect tank conversion chart, or theft. The data required by the model include only daily stick readings, deliveries, and sales.

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[8] Warren Rogers Associates, Inc., "Inventory Reconciliation System," (undated).

The basis for the model is that the major errors and discrepancies in the inventory data are very distinct in their characteristics and thus in the way they contribute to the total record. Thus, for example, an unrecorded over-delivery or an unrecorded removal will cause a permanent shift in the record which remains as a fixed component in all future observations. This effect can be estimated and removed from consideration when evaluating the possibility of a continuing day-to-day trend indicative of a leak. By contrast, a large stick error caused by a mistake in reading the stick or conversion chart will typically cause a large discrepancy in that day's inventory which will be followed the next day by a discrepancy of similar size in the opposite direction. The two discrepancies will tend to cancel out in the cumulative inventory record. The "signature" of a pump meter error is different: such an error will induce day-to-day errors of constant sign proportional to the through-put of the tank.

WRA's report to clients includes a record of day-to-day variances and the cumulative variance between book inventory and stick measurement for the period. It also provides:

- Over- or under-deliveries by date of occurrence and amount. That is, the discrepancy between the amount of product actually delivered as opposed to the amount reported;
- Unexplained one-time gains or losses also by date and amount;
- Meter errors at the pump;
- Trends which are indicative of either a tank or line leak; and
- Effects of possible disparities between the ambient air temperature and underground temperature.

As a special contribution to this study, WRA also provided a "data quality code" based on professional interpretation and experience. The data quality code is explained in Table E-7. A sample WRA inventory report is shown in Figure E-1. Based on a discussion with the developers of the WRA model, the false-positive rate is five percent, comparable to the modified EPA method.

Table E-7. WRA data quality code

Category	Definition
1	Confident of the result
2	The trend could have been delivery-induced
3	The trend is noisy but believable
4	No confidence in the trend due to the data
5	Data is questionable and requires further investigation.

III. ENTROPY LIMITED INVENTORY RECONCILIATION SYSTEM

Entropy Limited has developed the Precision Tank Inventory Control (PTIC) system[9]. The analysis is based on principles similar to the WRA system and accounts for the same types of errors and discrepancies. Entropy appears to consider thermal effects and vapor losses more comprehensively than does WRA. However, additional input data to the system is required for these analyses.

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[9] Entropy Limited, "Precision Tank Inventory Control," (1984).

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                WARREN ROGERS ASSOCIATES, INC                    PAGE   1
                     65 BELLEVUE AVENUE
                     NEWPORT, RI  02840
                      (401) 846-4747
                                                                10/27/85
                     INVENTORY ANALYSIS
                     ------------------

TANK ID :    1
PRODUCT :  UNLEADED

TANK SIZE:        10000

MONTH   DAY  SALES   DELIVERIES    STICK    BOOK  DAILY VARIANCE  CUM. VARIANCE
  4      3   1150.          0.     2926.   2901.            25.            25.
  4      4   1163.          0.     1733.   1738.           -30.            -5.
  4      5    628.          0.     1098.   1110.            -7.           -12.
  4      6   1444.       4100.     3759.   3766.             5.            -7.
  4      7    902.          0.     2864.   2864.             7.             0.
  4      8    466.          0.     2373.   2398.           -25.           -25.
  4      9   1055.          0.     1301.   1343.           -17.           -42.
  4     10    856.          0.      437.    487.            -8.           -50.
  4     11    524.       4230.     4152.   4193.             9.           -41.
  4     12   1285.       2060.     4948.   4968.            21.           -20.
  4     13   1195.          0.     3759.   3773.             6.           -14.
  4     14   1158.          0.     2616.   2615.            15.             1.
  4     15    630.       3750.     5744.   5735.             8.             9.
  4     16    921.          0.     4815.   4814.            -8.             1.
  4     17    784.          0.     4021.   4030.           -10.            -9.
  4     18   1453.          0.     2554.   2577.           -14.           -23.
  4     19    532.       5110.     7102.   7155.           -30.           -53.
  4     20   1028.          0.     6073.   6127.            -1.           -54.
  4     21    881.          0.     5214.   5246.            22.           -32.
  4     22    992.          0.     4218.   4254.            -4.           -36.
  4     23    488.          0.     3693.   3766.           -37.           -73.
  4     24   1169.       4100.     6594.   6697.           -30.          -103.
  4     25    528.          0.     6073.   6169.             7.           -96.
  4     26    827.          0.     5214.   5342.           -32.          -128.
  4     27    786.          0.     4416.   4556.           -12.          -140.
  4     28    661.          0.     3759.   3895.             4.          -136.
  4     29    842.       5240.     8125.   8293.           -32.          -168.
  4     30    827.          0.     7289.   7466.            -9.          -177.
  5      1   1401.          0.     5876.   6065.           -12.          -189.
  5      2   1051.          0.     4815.   5014.           -10.          -199.
                  END OF PERIOD CUMULATIVE VARIANCE

                              -199.

                  NUMBER OF NEGATIVE DAILY VARIANCES

                               19

                      DELIVERY DISCREPANCIES

                       MONTH     DAY      AMOUNT
                         4       12          46.
```

Figure E-1. WRA Inventory Report

```
                  WARREN ROGERS ASSOCIATES, INC              PAGE   2
                         65 BELLEVUE AVENUE
                         NEWPORT, RI  02840
                         (401) 846-4747                    10/27/85

                         INVENTORY ANALYSIS
                         ------------------

TANK ID :   1
PRODUCT :  UNLEADED

TANK SIZE        10000

                    MONTH     DAY       AMOUNT
                      4       29          -17.

               UNEXPLAINED ONE TIME GAINS AND LOSSES

                    MONTH     DAY       AMOUNT
                      4       14           39.
                      4       21           19.
                      4       23          -36.
                      4       26          -19.

                       PUMP METER ERROR

                             NONE

                          DAILY TREND

                             -8.37

                      AVERAGE STICK ERROR

                              6.95

                       LARGE STICK ERRORS

                         MONTH    DAY
                           4       19

                    TEMPERATURE DIFFERENTIAL

                             -2.66

                      SIGNIFICANCE OF TREND

                              0.00
```

1

The PTIC system reports its leak findings as an estimated leak rate, in gallons per day, and as a "probability of leak" (see the sample inventory report in Figure E-2). According to the model's developers, the probability of leak is based on a Bayesian-type analysis which accounts for various factors including the quality of the inventory data. Details are proprietary. Typically, the decision rule is phrased in terms of the leakage probability as follows:

Leak probability	Decision
< 10%	Tank is tight
10% - 50%	Inconclusive
≥ 50%	Tank is leaking

The 50 percent cutoff point corresponds to a false-positive rate of approximately two percent. To obtain a more typical five percent false-positive rate, a cutoff of 30 percent leak probability should be used to decide that the tank is leaking.

```
TANK # =  2      STAGE II VAP CONTROL LEVEL (9=NO VAP LOSS) =  1
TANK SIZE =      4000.     3 =REG UNLD, INSTYR=1973

INVENTORY RECORDED GALLONS:    0 = GROSS,   1 = NET
    0  DELIVERIES
    0  STICK INVENTORY
    0  DISPENSED PRODUCT

N.B.!!   STICK-READING AND TOTALIZING OCCURS ON THE MORNING AFTER THE LISTED DATE

  I      DATE   DISPENSED    STORAGE      DELIV    DISCREP
  1   1/ 2/85      147.8     1374.0        0.0        0.0
  2   1/ 3/85      147.8     1221.0        0.0       -5.2
  3   1/ 4/85      180.4      925.0        0.0     -115.6
  4   1/ 5/85      230.8      584.0        0.0     -110.2
  5   1/ 7/85      202.8     1846.0     1100.0      364.8
  6   1/ 8/85      156.4     1766.0        0.0       76.4
  7   1/ 9/85       86.0     1569.0        0.0     -111.0
  8   1/10/85      121.5     1374.0        0.0      -73.5
  9   1/11/85      179.8     1108.0        0.0      -86.2
 10   1/12/85      134.4      925.0        0.0      -48.6
 11   1/14/85      192.9      649.0        0.0      -83.1
 12   1/15/85      230.3      289.0        0.0     -129.7
 13   1/16/85      232.5     1569.0     1100.0      412.5
 14   1/17/85      160.1     1297.0        0.0     -111.9
 15   1/18/85       84.1     1221.0        0.0        8.1
 16   1/19/85      180.8      961.0        0.0      -79.2
 17   1/21/85      174.7      716.0        0.0      -70.3
 18   1/22/85      111.7      521.0        0.0      -83.3
 19   1/23/85      291.5     1687.0     1100.0      357.5
 20   1/24/85      177.5     1451.0        0.0      -58.5
 21   1/25/85      201.5     1145.0        0.0     -104.5
 22   1/26/85      130.2      961.0        0.0      -53.8
 23   1/28/85      181.6      682.0        0.0      -97.4
 24   1/29/85      184.2      429.0        0.0      -68.8
 25   1/30/85      283.9     1530.0     1100.0      281.9
 26   1/31/85      224.5     1297.0        0.0       -8.5
 27   2/ 1/85       46.1     1221.0        0.0      -29.9
 28   2/ 2/85      112.0     1034.0        0.0      -75.0
 29   2/ 3/85      194.5      784.0        0.0      -55.5
 30   2/ 4/85      239.7     2005.0     1100.0      360.7
 31   2/ 5/85      120.5     1806.0        0.0      -78.5
TOTALS
        EVCT    DISPENSED    STORAGE      DELIV    DISCREP
        30.0       5191.7      432.0     5500.0      123.7

DISCREP DISTRIBUTION
  NUMBER OF DAYS WITH (+) DISCREP =   7  ( 23.3%)
  NUMBER OF DAYS WITH (-) DISCREP =  23  ( 76.7%)

DV STATS
DV = DISCREP (GAL) CORRECTED FOR TEMP, VAPOR LOSS AND WATER INFLOW
DV COUNTS =                        30.00000
DV AVG =                            4.00511
DV S.D. (BIASED) =                164.96200
DV VARIANCE (BIASED) =          27212.47
LAG-1 AUTOCORR =                   -0.19435
```

Figure E-2. Entropy Limited Inventory Report

```
DV DISTRIBUTION
  NUMBER OF DAYS WITH (+) DV =   7  ( 23.3%)
  NUMBER OF DAYS WITH (-) DV =  23  ( 76.7%)

DIPSTICK READ ERRORS
   NONE

DELIVERY DISCREPANCIES
   5    1/ 7/85        389.75  =DELIVERY OVER(+) OR UNDER(-)
  13    1/16/85        425.84  =DELIVERY OVER(+) OR UNDER(-)
  19    1/23/85        411.26  =DELIVERY OVER(+) OR UNDER(-)
  25    1/30/85        347.07  =DELIVERY OVER(+) OR UNDER(-)
  30    2/ 4/85        401.91  =DELIVERY OVER(+) OR UNDER(-)

UNEXPLAINED ONE-TIME DISCREPANCY
   NONE
UNMODIFIED DISCREPANCIES
DISCREPANCIES CORRECTED FOR TEMP, VAP, CHART CALIB AND METER ERR

SOURCES OF INVENTORY DISCREPANCIES

  1  LEAK RATE (GAL/DAY) =                               ESTIMATE     UNCER
  2  CALIB CHART ERR (100%*GAL/GAL-THRU) =                53.160      6.578
  3  TOTAL METER ERR (100%*GAL/GAL-THRU) =                 3.15       1.51
  4  THERMAL SHRINKAGE LOSS (GAL) =                       00.00      00.00
  5  VAPOR LOSS (GAL) =                                   -9.0       17.3
  6  NET DELIVERY DISCREPANCY (GAL) =                      5.5        9.8
  7  ONE-TIME UNEXPLAINED GAIN/LOSS (GAL) =             1975.8       83.6
  8  WATER INFLOW TO TANK (GAL) =                          0.0        0.0
  9  WATER OUTFLOW FROM TANK (GAL) =                       0.0        0.0
                                                           0.0        0.0
RECORDKEEPING FLAGS:
  EXCESSIVE DELIVERY DISCREPANCIES
  EXCESSIVE VARIANCE IN STICK READINGS

PROBABILITY OF TANK LEAKAGE=              100.00%
PROBABLE TANK LEAKAGE
```

APPENDIX F

DATA COLLECTION FORMS AND MATERIALS

APPENDIX F

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

THE ADMINISTRATOR

OCT 15 1984

OPEN LETTER TO OWNERS AND MANAGERS OF UNDERGROUND MOTOR FUEL STORAGE TANKS

The Environmental Protection Agency (EPA) is conducting a national survey to learn more about the problem of leaking underground motor fuel storage tanks and piping. The purposes of the study are to find out how widespread the leakage problem is, and to collect information on factors that cause tanks to leak. The study will help the Agency assess the impact of leaking tanks on the economy and the environment, and the need for Federal regulations to prevent leaking tanks.

I am writing to personally ask for your participation in this vital project, the results of which could have a major impact as to how we deal with this potential environmental threat.

Let me assure you that EPA is not conducting this survey to locate owners of leaking tanks to take legal action against them. To do so would defeat the purpose of the survey. In the case of leaking tanks, however, EPA will request that the owner report any leak to the proper local authority and take corrective action such as tank repair, replacement or removal from use.

In order to conduct this study, EPA has selected a random sample of about 1,000 establishments nationwide including farms, gasoline service stations, transportation-related businesses, businesses with private gas pumps, and government facilities. The sample of 1,000 establishments was selected to represent as many types of underground storage tank facilities as possible in order to develop national estimates of leakage on a scientific basis. Your establishment is one of the 1,000 selected to participate in this important study.

Within the next 2 weeks, an interviewer from Westat, Inc., a private contractor conducting the survey for EPA, will be contacting you to schedule an appointment for an interview with you at your place of business. A copy of the interview form is enclosed. We would appreciate it if you would take the time to fill out the questionnaire before the interviewer arrives, but do not mail the questionnaire back to EPA. The interviewer will review your answers with you during the visit.

In addition to the interview, the interviewer will be making a sketch map of your facility layout, and will want to know where each of your tanks is located. It would be helpful if you have a map of your tank and dispenser layout ready to show the interviewer.

As part of the survey, we will be asking you to provide product inventory records for a 30-day operating period, so it is necessary that we know the accuracy of your pump readings. If the calibration of your pump (or dispenser) meters has not been checked and certified within the past three months, the interviewer will need to check the meter calibration with a certified 5-gallon metering can.

Your inventory data for each tank system will be analyzed by computer to identify and explain any shortages or overages. Results of the analyses will be provided to you at no cost and will be confidential if you so request. Later, we will want to conduct professional tightness tests on some fraction of the tanks inventoried in the survey. All tests will be provided free to the participant, and, if requested, results will be treated as confidential by the Agency.

The enclosed booklet of General Instructions will provide you with definitions of key terms, answers to questions you might have about the survey, and directions on completing the questionnaire and providing inventory information. If you have any further questions about this questionnaire, or need any other assistance, please call Westat at the toll-free survey assistance number 800/638-8985, and ask for the EPA Specialist.

You may claim confidentiality for all or any part of your response under 40 CFR Part 2. You should do this when you provide the information to the interviewer. A confidentiality request form is included in the instructions booklet.

Although EPA is conducting the survey under Federal authority, we are seeking your full and active participation on a cooperative basis. I hope we can count on your help.

Enclosures

Sincerely,

William D. Ruckelshaus

U.S. ENVIRONMENTAL PROTECTION AGENCY
UNDERGROUND STORAGE TANK SURVEY

GENERAL INSTRUCTIONS

Prepared by:

WESTAT
An Employee-Owned Research Corporation
1650 Research Blvd • Rockville MD 20850 • 301 251-1500

407

GENERAL INSTRUCTIONS FOR COMPLETING THE ESTABLISHMENT OPERATOR'S QUESTIONNAIRE

PLEASE READ THE FOLLOWING INSTRUCTIONS BEFORE YOU BEGIN TO FILL OUT THE ENCLOSED QUESTIONNAIRE. IF YOU SHOULD NEED FURTHER ASSISTANCE, CALL WESTAT AT THE TOLL FREE SURVEY ASSISTANCE NUMBER, (800) 638-8985, AND ASK FOR THE EPA SURVEY SPECIALIST.

PURPOSE OF THE SURVEY

The Environmental Protection Agency (EPA) is conducting this study to learn more about the problem of leakage in underground storage tanks. The purposes of this study are to find out how widespread the leakage problem is, and to collect information on factors that cause tanks to leak. The study will help the Agency assess the impact of leaking tanks on the economy and the environment, and the need for Federal regulations to prevent leaking tanks.

HOW ESTABLISHMENTS WERE SELECTED

Establishments were selected to participate in this survey from a preliminary listing of facilities that are likely to have underground storage tanks. This list was compiled by EPA from a variety of sources, including government agencies, federal program rosters, and private and telephone directories. Your facility was not purposely chosen from this listing, but sampled on a probability basis using scientific random selection procedures. The purpose of the probability selection procedures is to obtain a broad representation of kinds of establishments with underground motor fuel storage tanks.

If your company operates more than one establishment that has underground motor fuel storage tanks, the establishment you are to respond for can be identified by the facility's name and address on the questionnaire label. If the questionnaire label does not provide you with enough information to know which establishment to respond for, please call the EPA Survey Specialist at the toll free hot line number, (800) 638-8985.

HOW THIS SURVEY WILL BE CONDUCTED

Within the next two weeks, an interviewer from Westat, Inc. will be contacting you to arrange an appointment for an in-person interview with you at the establishment location. (Westat, Inc. is a survey research company that is assisting the EPA in conducting the Underground Storage Tank Survey.) Enclosed with this instruction booklet is a copy of the questionnaire, so that you will know what questions the interviewer will ask. In order to answer some of the questions, you may need to consult your records, so you should prepare your answers to the interview before the interviewer calls. Since the interviewer will record your answers in a separate copy of the interview, the enclosed copy is yours to keep.

AUTHORITY

This survey is being conducted under authority of Sections 9005 and 9009 of the Resource Conservation and Recovery Act (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984. Subsections (a) and (b) of Section 9005 detail EPA's authority for conducting the survey and the conditions under which EPA will treat information provided by owners and operators as confidential business information (see CONFIDENTIALITY). Section 9009 details EPA's responsibilities in conducting studies of underground storage tanks.

REIMBURSEMENT

Section 9009(f) specifies that owners or operators of underground storage tanks shall be provided "fair and equitable reimbursement" for "costs, including the loss of business opportunity, due to closure or interruption of operation of an underground storage tank solely for the purpose of conducting studies authorized by this Section." Under Section 9009(f)(2), claims for reimbursement must be "filed with the Administrator [of EPA] not later than 90 days after the closure or interruption which gives rise to the claim."

CONFIDENTIALITY

Section 9005(b) of RCRA, as ammended requires EPA to make survey information available to the public upon request, unless you have requested that the information be treated as confidential business information under 40 CFR, Part 2 and Section 1905 of Title 18 of the United States Code. As explained in the Administrator's open letter, you can request that all of the information you provide be treated as confidential business information, or that certain items be treated as such. Information that has been determined by EPA to be confidential business information cannot be made available to the public by EPA, but can be made available to authorized officers, employees and representatives of EPA, and to the Congress, if requested.

Although EPA is conducting this survey under Federal authority, we are seeking your participation on a cooperative basis. Be assured that the contractor and staff conducting the survey are pledged not to disclose the name or address of any participant. The contractor provides survey data to EPA identified only by a participant code number. Only if an establishment refuses to participate will the name and address be given to EPA. Should this occur, the Agency may be required to take legal steps to obtain data necessary to the survey. However, we would use legal action as a last resort and would strive to avoid its use.

If you want to request that some or all of the information you provide will be treated as confidential business information, please read and complete the "Request for Confidential Treatment of Business Information" form enclosed with this package. You should give the completed, signed request form to the interviewer at the time of the interview.

REQUEST FOR CONFIDENTIAL TREATMENT OF BUSINESS INFORMATION

I hereby request that information I have provided to the Environmental Protection Agency in response to (certain/all) the questions in the "Underground Storage Tank Establishment Operator's Questionnaire" or the "Inventory Record Form" be treated as confidential business information under 40 CFR Part 2, and Section 1905 of Title 18 of the United States Code.

LIST THE QUESTION NUMBERS OF THE RESPONSES FOR WHICH YOU ARE REQUESTING CONFIDENTIAL TREATMENT: ____________________

____

____

____

PLEASE PRINT OR TYPE:

ESTABLISHMENT NAME: ____________________

MAILING ADDRESS: ____________________
Street

____________________ ____________________ ☐☐☐☐☐
City State Zip

TELEPHONE: ☐☐☐ - ☐☐☐ - ☐☐☐☐ ____________
Extension

ESTABLISHMENT OWNER/
OPERATOR: ____________________ ____________________
(Print or type) (Signature)

DATE: ____ / ____ / ____
Month Day Year

F-15

DEFINITION OF TERMS

Cathodic Protection - Used to reduce or eliminate corrosion of a metallic structure which is in contact with corrosive soil by applying an electric current to the structure which is greater in strength and opposite in direction to the current that is causing corrosion.

Passive (galvanic) Cathodic Protection - The required current is generated by the corrosion of sacrificial anodes, such as Magnesium or Zinc, which are attached to the surface of the protected material (tank or pipe) in the soil.

Impressed Current Cathodic Protection - The required current is provided by an external source and is passed through the system using non-sacrificial anodes, such as Carbon or Platinum, which are buried in the ground.

Continuous Electronic Monitoring System - This system could include the following:

- thermal conductivity sensors;
- electrical resistivity sensors;
- gas detector; and
- interstitial monitoring in double-walled tanks.

Establishment - The term establishment is used to mean a commercial or non-commercial location that is used for any purpose other than just a residence. That is, any location that is used for a nonresidential purpose (even if it is also used as a residence) is considered to be an establishment. Examples of establishments include gasoline service stations, farms, schools, factories, fire stations, highway maintenance facilities, parks, stores, offices, delivery services, military installations, airports, etc. (If you believe that your facility does not fit the definition of an establishment, please call the toll free survey assistance number, (800) 638-8985, and explain your situation to the EPA Survey Specialist.)

External Corrosion Protection System - This system could include the following special equipment or materials:

- cathodic protection;
- electric isolotion;
- polyethylene wrappings;
- coatings; and
- paints.

Inventory Reconciliation - The balancing of "book" inventories against observed inventories (meter/dipstick readings).

Manway - A means of entrance into an underground storage tank allowing internal inspection.

Motor Fuel - Any substance that is used to power a motorized vehicle (such as an automobile, boat, airplane, truck, etc.). For example, motor fuels such as:

- leaded gasoline;
- unleaded gasoline;
- diesel fuel;
- aviation gas;
- jet fuel; and
- gasohol.

Pressure Pump Delivery System (also called submerged pump delivery system) - This system works on the principle of positive pressure to push the liquid from a low point to a high point using a submerged pump (coupled with an electric motor) mounted inside the tank.

Remote Gauge - A measuring device that indicates the quantity of fuel stored in a tank on an external scale or dial.

Secondary Containment - A secondary enclosure or barrier intended to contain any spills or leakage from the primary storage tank or from pumps, piping and other equipment. These may include:

- concrete vaults or basins;
- plastic or clay lined basins;
- soil sealants (soil cement or bentonites); or
- double-walled tanks or pipes.

Siphon Pump Delivery System (also called suction pump delivery system) - This system works by drawing liquid from a low point because of a vacuum at a high point, using a suction pump. This pump is located at grade (i.e., ground level), either directly above the storage tank or, as in the case of some dispensing operations, at some distance from the storage tank (at the pump islands).

Underground Storage Tank - A large vessel or container placed beneath the surface of the earth used for storing and handling of liquids (such as petroleum products) or waste materials (such as used or waste oil).

Used or Waste Oil - Oils (whether used or unused) that are no longer fit for their intended use because of contamination or degradation. These oils include, but are not limited to:

- automotive engine oils;
- gear lubricants;
- diesel engine oils;
- railway diesel oils;
- oil storage and treatment residuals (such as bottoms);
- hydraulic oils;
- metal working oils;
- transformer oils; and
- oils contaminated with water.

Water Finding Paste - A paste applied to the bottom of the dipstick which changes color when it comes in contact with water.

Water Table - The upper limit of the portion of the ground (soil) wholly saturated with water.

ORGANIZATION OF THE QUESTIONNAIRE

The Establishment Owners/Operators Questionnaire is designed to obtain data on your establishment's underground fuel and waste oil storage operation, including such items as tank design, operating and installation characteristics, tank corrosion protection and tank leakage monitoring. The questionnaire is divided into seven sections, as follows:

A. Screening Information

This section of eleven questions asks for information about the establishment itself, including questions about the type of establishment, the owner and operator of the establishment, and the number of tanks at the establishment. Question A.11 provides instructions for completing Tank Description Sheets for the establishment.

Tank Description Sheets - A Tank Description Sheet must be completed for each underground tank. Questions asked will include information on specific tank characteristics, such as reported age, size and typical fill volume, manufacturer, installer, materials of construction, inspections or leak tests, and other design characteristics.

B. Operating Practices

This section asks questions about practices such as taking tank inventories using a dipstick, checking and recording dispenser meter readings, inventory procedures after a delivery and inventory reconciliation or "balancing" between stick readings, dispenser meter readings, and delivery records.

C. Operating History

In this section you will be asked about any tanks that have been replaced, removed without being replaced, or abandoned in place, and in what year and why this occurred.

D. Permits and Licenses

This is a short section about any special permits or licenses needed for tank installation or storage of flammable materials.

E. Installation

Section E includes overall questions about how the tank was installed.

F. Protection

This section asks questions about any protection systems in use against external corrosion, and any monitoring systems used to detect tank leakage.

G. Information Needs

Section G is about the kinds of information and services relating to tank monitoring that are currently available to you.

USE OF THE QUESTIONNAIRE

The questionnaire has been designed to minimize the effort required for it's completion. "Skip patterns" have been incorporated to enable respondents to by-pass sections of the questionnaire which are not relevant to them. The following section describes how you are to complete the questionnaire in preparation for the call from a Westat interviewer.

EXAMPLES OF QUESTIONS

Most of the questionnaire items are straightforward and require only the circling of the correct code(s) or the completion of short answers on the lines which are provided. The following examples illustrate the use of other question formats found throughout the questionnaire.

Example A

Some questions require that you indicate a distance or frequency and also circle the correct unit of measurement or time as indicated in the sample questions below. Different units have been specified for your convenience. Please do not neglect to circle a unit code (as shown) or to write in an appropriate unit of measurement or time. This question, as with all questions, includes its own instructions printed in capital letters and enclosed in brackets.

E4. What is the shortest distance between any of your tanks and any neighboring underground tank or other solid underground structure (such as a basement wall, sewer, or utility vault)? [ENTER DISTANCE AND CIRCLE UNIT CODE]

SHORTEST DISTANCE FROM UNDERGROUND STRUCTURE: 6 /23-2

[CIRCLE ONE]:
INCHES. 01
[✓ FEET. 02] /29-3
OTHER [SPECIFY]: ________________ 03
____

F2. How often do you inspect your external corrosion protection system? [ENTER FREQUENCY AND CIRCLE UNIT CODE]

> IF YOU NEVER INSPECT THE EXTERNAL CORROSION PROTECTION SYSTEM, CHECK HERE ☐ AND SKIP TO F3.

/19

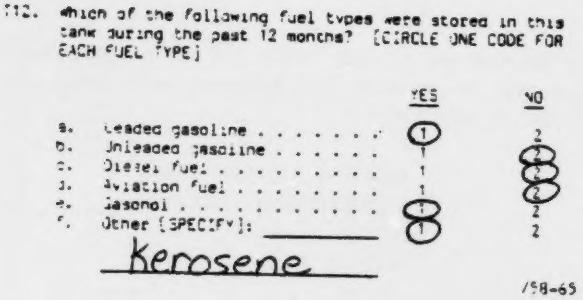
FREQUENCY OF INSPECTION: 2 /20-22

[CIRCLE ONE]:

PER DAY	01	
PER WEEK.	02	
PER MONTH	[✓ 03]	/23-24
PER YEAR.	04	
OTHER [SPECIFY]: ______________	05	

Example B

Other questions require that you code a "yes or "no" answer for each category listed, as indicated in the sample question below. The "Other [SPECIFY]" line enables you to enter an answer not covered by the preprinted response categories.



F12. Which of the following fuel types were stored in this tank during the past 12 months? [CIRCLE ONE CODE FOR EACH FUEL TYPE]

		YES	NO
a.	Leaded gasoline	[✓ 1]	2
b.	Unleaded gasoline	1	[✓ 2]
c.	Diesel fuel	1	[✓ 2]
d.	Aviation fuel	1	[✓ 2]
e.	Gasohol	[✓ 1]	2
f.	Other [SPECIFY]: Kerosene	[✓ 1]	2

/58-65

Example C

When a series of similar questions apply consistently to a given category, they have been formatted into tables or grids to facilitate the administration of the questions. Notice also that Question C6b requests that all applicable response categories be circled, not just the most prominent one, as indicated in the sample question below.

C6. Please answer the following questions about each tank that has been removed without being replaced. [SPACE HAS BEEN PROVIDED FOR UP TO FOUR TANKS. IF MORE THAN FOUR TANKS HAVE BEEN REMOVED WITHOUT BEING REPLACED, WRITE THE ANSWERS FOR THE ADDITIONAL TANKS ON A PLAIN SHEET OF PAPER]

	First Tank	Second Tank	Third Tank	Fourth Tank
C6a. In what year was the (first/second/third) tank removed?	74 (year) /20-23	74 (year) /34-37	81 (year) /48-51	(year) /62-65
C6b. Why was the tank removed? [CIRCLE ALL THAT APPLY FOR EACH TANK]				
a. Because it was leaking?. . . .	01	[✓ 01]	[✓ 01]	01
b. Because other tanks were being removed at that time? . . .	[✓ 02]	02	02	02
c. Because it was no longer needed/in use?.	03	03	[✓ 03]	03
d. Or for some other reason [SPECIFY]: .	04	04	04	04
	(specify) /24-33	(specify) /38-47	(specify) /52-61	(specify) /66-74

SKIP INSTRUCTIONS

Skip instructions indicate the next question to be answered. They save time by allowing you to ignore irrelevant questions. The following is an example of a skip instruction attached to an answer category.

B1. Do you (or another establishment employee) inventory the contents of your tank(s) by measuring the depth of the contents with a dipstick? [CIRCLE ONLY ONE CODE]

YES [GO ON TO B2]. . . . . 1 /16
NO [SKIP TO B5] . . . . [✓ 2]

Skip instructions are sometimes not attached to an answer but are enclosed in a box, as shown below.

B14. How often is the accuracy of your dispenser meters checked? [CIRCLE ONLY ONE CODE]

IF THE ACCURACY OF YOUR DISPENSER METERS IS NEVER CHECKED, CHECK HERE ☑ AND SKIP TO B16. /32

DAILY. 01
WEEKLY 02
EVERY TWO WEEKS. 03
MONTHLY. . . . . 04 /33-34
ANNUALLY 05
OTHER [SPECIFY]: ____________________ 06

THE MOTOR FUEL INVENTORY SHEETS

Enclosed in the survey package are four kinds of sheets for keeping daily motor fuel inventory records. The type of tank and dispenser systems you operate will determine which inventory sheet(s) you will need to use. You may need only one kind of sheet or as many as three kinds.

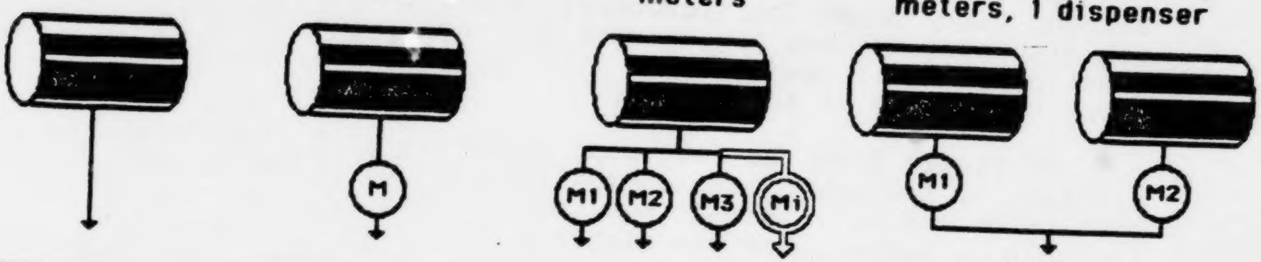
In Figure 1 on the following page, you will find schematic diagrams of the seven most common tank and dispenser hookup systems currently in use. These seven hookup systems are listed in Table 1, below. Use the diagrams in Figure 1 to determine which tank and dispenser hookup system(s) you have. Then use Table 1 to determine which kind(s) of sheet(s) you should use for inventory recording.

Table 1. Inventory Recording

	Appropriate Inventory Review Forms			
Possible tank/Dispenser Meter/ Dispenser Hookups	Inventory Sheet for Tanks without Metered Dispensing Pumps	Inventory Sheet for Tanks with Metered Dispensing Pumps	Dispensing Meter Recording Sheet	Manifolded Tank System Recording Sheet
Single tank, unmetered	X			
Single tank with single dispensing meter		X	X	
Single tank with multiple dispensing meters		X	X	
Custom Blending: 2 tanks, 2 dispensing meters, 1 dispenser		X	X	
Custom Blending: 2 tanks, multiple dispensing meters and dispensers		X	X	
Manifolded Tanks: Multiple interconnected tanks, multiple dispensing meters		X	X	X
Manifolded Tanks, Custom Blending		X	X	X

Figure 1

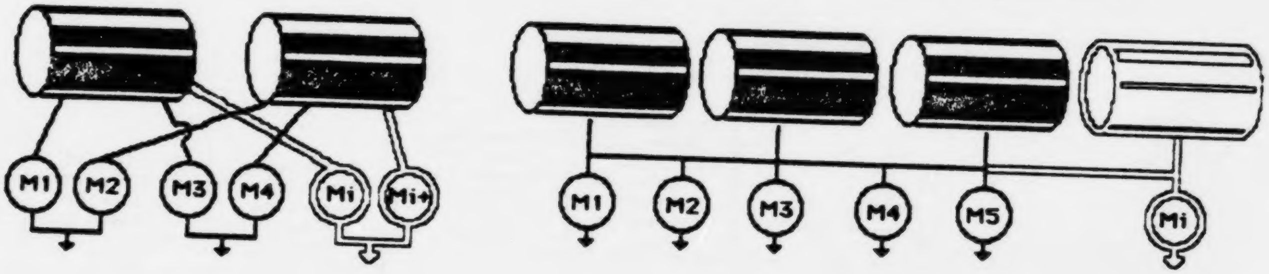
Schematic Diagrams of Possible Tank/ Dispensing Meter/Dispenser Hookup


Single tank, unmetered

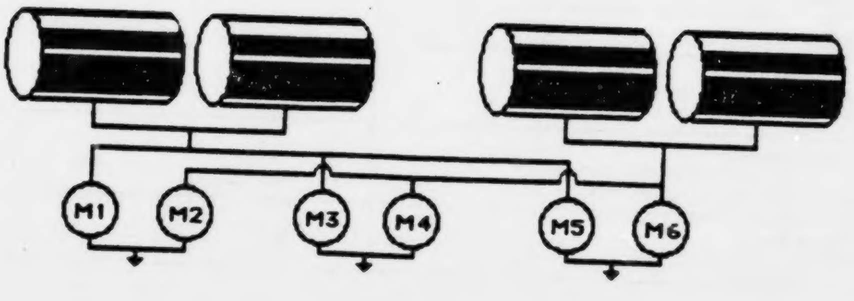
Single tank, single dispensing meter

Single tank, multiple dispensing meters

Custom Blending: 2 tanks, 2 dispensing meters, 1 dispenser
M
M1
M2
M3
Mi
M1
M2


Custom Blending: 2 tanks, multiple dispensing meters and dispensers

Manifolded Tanks: multiple interconnected tanks, multiple dispensing meters
M1
M2
M3
M4
Mi
Mi+
M1
M2
M3
M4
M5
Mi


Manifolded Tanks, Custom Blending
M1
M2
M3
M4
M5
M6

Regardless of which inventory sheets you use, you will need to provide 30 complete inventory readings for each of your tanks. It is preferable that each of these readings represents one operating day. Many tanks and tank systems are inactive (not used) for certain days during the week. If your tank(s) are inactive on a particular day, you can use the inactive day as an inventory day only if you take and record dipstick readings for the tank(s) for that day. (You cannot carry down the closing stick readings from the previous day.) You must provide actual stick readings (or remote gauge readings, if available) for each of the 30 inventory days. If your dispensers are metered, you must also provide meter readings for each of the 30 inventory days. If you do not have complete inventory information for a day, do not use that day as an inventory day.

Instructions for using each of the four kinds of Motor Fuel Inventory Sheets, along with example copies of the Sheets, are provided on the following pages of this booklet. After you have used Figure 1 and Table 1 to determine which inventory sheets you will be using, please read the instructions on how to complete the sheets.

If you have any questions about:

- Which sheets you should use for your tanks;
- How to complete the sheets; or
- Any recording problems you may have;

please call Westat at the toll-free survey assistance number, (800) 638-8985, and ask for the EPA Survey Specialist.

INSTRUCTIONS FOR COMPLETING THE INVENTORY SHEET FOR TANKS WITH METERED DISPENSING PUMPS

The Inventory Sheet for Tanks with Metered Dispensing Pumps is used for any individual tank or system of connected tanks (i.e., manifolded tanks) that has one or more metered dispensing pumps. The sheet is used to record daily physical inventory measurements (stick readings and deliveries) and volume of fuel pumped from the tank, as calculated from dispensing meter readings. You will need one Inventory Sheet for Tanks With Metered Dispensing Pumps for each tank (or system of tanks) that has metered dispensers.

You should fill out one line of the Inventory Sheet for each day that inventory readings are taken. (Days for which inventory readings are not taken should not be entered on the sheet.)

- In Column 1, enter the date of the reading (day and month).
- In Column 2, enter the opening dipstick reading, in gallons. (On days 2 through 30, opening dipstick reading will be the same as the closing stick reading of the line above.)
- In Column 3, enter the day's deliveries to the tank, in gallons.
- In Column 4, enter the sum of Columns 2 and 3. (This is your "opening physical inventory."
- In Column 5, enter your closing dipstick reading to the nearest quarter inch.
- In Colunn 6, enter your closing dipstick reading, converted to gallons (using your conversion chart for this tank).
- In Column 7, subtract the amount in Column 6 (your closing stick inventory) from the amount in Column 4 (your opening physical inventory) and write the remainder in Column 7. This column represents the quantity gone from the tank, according to your physical inventory records.

- In Column 8, enter the "meter sales" (the number of gallons pumped from the tank according to your meter readings). You must record the actual meter readings and calculate the meter sales on a Dispenser Meter Recording Sheet. Column 8 of the Inventory Sheet should equal Line I of the Dispenser Meter Recording Sheet for the same date.

The Inventory Sheet for Tanks With Metered Dispensing Pumps is printed as a four-page booklet along with a Dispenser Meter Recording Sheet. (The dispenser Meter Recording Sheet is the last three pages of the booklet.) Six copies of the Inventory and Dispenser Sheet booklet are included in the survey package. If there are more than six tanks with metered dispensers at your establishment, please photocopy as many additional sheets as are required.

INVENTORY SHEET FOR TANKS WITH METERED DISPENSING PUMPS

Tank Number: ____________

Dispenser Meter Numbers: ____________

____

____
(Name of Facility)

____
(Street Address)

____
(City/Town) (State) (Zip)

Type of Fuel: ____________

Size of Tank: ____________

Year Installed: ____________

		Dipstick* Inventory						
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
Day	Date	Opening Dipstick* Inventory (gallons)	Deliveries (in gallons)	[Column 2] plus [Column 3]	Closing Dipstick* Inventory (inches)	Closing Dipstick* Inventory (gallons)	Gone from Tank: [Column 4] minus [Column 6]	Meter sales** (gallons) (from meter sheet)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								

*If tank has remote gauge, check here ☐ and use remote gauge readings instead of stick readings.

**Transferred from Line I of Dispenser Meter Recording Sheet.

INSTRUCTIONS FOR COMPLETING DISPENSER METER RECORDING SHEET

The Dispenser Meter Recording Sheet is used to record daily meter readings and to calculate volume of fuel pumped for all dispenser meters connected to an individual tank or system of tanks. One 30-day set of Meter Sheets is kept for each individual tank or connected tank system. On each day of inventory readings, record each meter's closing reading (in gallons) on Line G ("Today's Closing Meter"). Record "Yesterday's Closing Meter" on Line H. (For Day 2 through Day 30, "Yesterday's Closing Meter" will be the same as Line G ["Today's Closing Meter"] from the day before.)

The gallons of fuel dispensed daily through a given meter is calculated by subtracting "Yesterday's Closing Reading" (Line H) for that meter from its "Today's Closing Reading" (Line G). Enter the difference between the two readings in Line I for each meter. This is the number of gallons dispensed (pumped) through that meter during that day. After you have entered the gallons dispensed by each meter in Line I, add up Line I for all meters and enter that figure in the column marked "Line I Totals." The "Line I Total" figure is the daily "gallons dispensed" for all meters. The "Line I Total" must also be recorded for the same day in Column 8 of the Inventory Sheet for this tank.

Dispenser Meter Recording Sheets are printed in a four-page booklet, along with an Inventory Sheet. Six copies of this booklet are included in the survey package. Please photocopy extra copies if needed.

DISPENSER METER RECORDING SHEET

[FOR TANKS WITH METERED DISPENSING PUMPS]

Tank* No.: ____________________

Type of Fuel: ____________________

Day	Date	Meter Recordings in Gallons	Meter #1	Meter #2	Meter #3	Meter #4	Meter #5	Meter #6	Meter #7	Meter #8	Line I** Totals
1		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
2		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
3		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
4		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
5		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
6		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
7		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
8		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
9		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
10		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									

*For a manifolded tank system, list the numbers of all of the tanks in the system.

**Transfer Line I totals to Column 8 of Inventory Sheet.

DISPENSER METER RECORDING SHEET

[FOR TANKS WITH METERED DISPENSING PUMPS]

Tank* No.: ____________

Type of Fuel: ____________

Day	Date	Meter Recordings in Gallons	Meter #1	Meter #2	Meter #3	Meter #4	Meter #5	Meter #6	Meter #7	Meter #8	Line I** Totals
11		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
12		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
13		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
14		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
15		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
16		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
17		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
18		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
19		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
20		G. Today's Closing Meter									
		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									

*For a manifolded tank system, list the numbers of all of the tanks in the system.

**Transfer Line I totals to Column B of Inventory Sheet.

DISPENSER METER RECORDING SHEET

(FOR TANKS WITH METERED DISPENSING PUMPS)

Tank* No.: ______________________

Type of Fuel: ______________________

Day	Date	Meter Recordings in Gallons	Meter #1	Meter #2	Meter #3	Meter #4	Meter #5	Meter #6	Meter #7	Meter #8	Line I** Totals
		G. Today's Closing Meter									
21		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
		G. Today's Closing Meter									
22		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
		G. Today's Closing Meter									
23		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
		G. Today's Closing Meter									
24		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
		G. Today's Closing Meter									
25		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
		G. Today's Closing Meter									
26		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
		G. Today's Closing Meter									
27		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
		G. Today's Closing Meter									
28		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
		G. Today's Closing Meter									
29		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									
		G. Today's Closing Meter									
30		H. Yesterday's Closing Meter									
		I. Gallons Dispensed (G - H)									

*For a manifolded tank system, list the numbers of all of the tanks in the system.

**Transfer Line I totals to Column 8 of Inventory Sheet.

INSTRUCTIONS FOR COMPLETING THE MANIFOLDED TANK SYSTEM RECORDING SHEET

The Manifolded Tank System Recording Sheet is an eight-page booklet that is used whenever two or more tanks are connected by piping to make a multiple or manifolded tank system. One Manifolded Tank System Recording Sheet booklet is to be used for each manifolded tank system that is to be inventoried.

The purpose of the Manifolded Tank System Recording Sheet is to provide a convenient way to keep individual daily stick and delivery records for each tank in the system. At the end of each day, you should add up and record each line of inventory measurements (Lines A through F) for all tanks in the manifolded system. These daily totals are entered in the "Tank System Totals" column of the Manifolded Tank System Recording Sheet, and then transferred to the appropriate columns of the Inventory Sheet for the tank systems. The "Transfer to Inventory Sheet" column on the righthand side of the sheet indicates that Inventory Sheet column number to which the total should be transferred. You must also complete a Dispenser Meter Recording Sheet for the tank system.

MANIFOLDED TANK SYSTEM RECORDING SHEET

Tank Numbers of Tanks in This Manifolded System: ______________________________

Type of Fuel: ______________________

Day	Date	Meter Recordings in Gallons	Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank System Totals	Transfer to Inventory Sheet
		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
1		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
2		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
3		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
4		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7

*Transfer Tank System Totals to the indicated columns on the correct Inventory Sheet for this Tank System.

MANIFOLDED TANK SYSTEM RECORDING SHEET

Day	Date	Meter Recordings in Gallons	Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank System Totals	Transfer to Inventory Sheet
5		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
6		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
7		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
8		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7

*Transfer Tank System Totals to the indicated columns on the correct Inventory Sheet for this Tank System.

MANIFOLDED TANK SYSTEM RECORDING SHEET

Day	Date	Meter Recordings in Gallons	Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank System Totals	Transfer to Inventory Sheet
9		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
10		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
11		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
12		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7

*Transfer Tank System Totals to the indicated columns on the correct Inventory Sheet for this Tank System.

MANIFOLDED TANK SYSTEM RECORDING SHEET

Day	Date	Meter Recordings in Gallons	Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank System Totals	Transfer to Inventory Sheet
13		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
14		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
15		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
16		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7

*Transfer Tank System Totals to the indicated columns on the correct Inventory Sheet for this Tank System.

MANIFOLDED TANK SYSTEM RECORDING SHEET

Day	Date	Meter Recordings in Gallons	Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank System Totals	*Transfer to Inventory Sheet
17		A. Opening Stick (gals) (Yesterday's Line E)										
		B. Deliveries (gals)										Col 2
		C. Total of Fuel in Tank (A + B)										Col 3
		D. Closing Stick (inches)										Col 4
		E. Closing Stick (gals)										Col 5
		F. Fuel Gone from Tank (gals) (C - E)										Col 6
18		A. Opening Stick (gals) (Yesterday's Line E)										Col 7
		B. Deliveries (gals)										Col 2
		C. Total of Fuel in Tank (A + B)										Col 3
		D. Closing Stick (inches)										Col 4
		E. Closing Stick (gals)										Col 5
		F. Fuel Gone from Tank (gals) (C - E)										Col 6
19		A. Opening Stick (gals) (Yesterday's Line E)										Col 7
		B. Deliveries (gals)										Col 2
		C. Total of Fuel in Tank (A + B)										Col 3
		D. Closing Stick (inches)										Col 4
		E. Closing Stick (gals)										Col 5
		F. Fuel Gone from Tank (gals) (C - E)										Col 6
20		A. Opening Stick (gals) (Yesterday's Line E)										Col 7
		B. Deliveries (gals)										Col 2
		C. Total of Fuel in Tank (A + B)										Col 3
		D. Closing Stick (inches)										Col 4
		E. Closing Stick (gals)										Col 5
		F. Fuel Gone from Tank (gals) (C - E)										Col 6
												Col 7

*Transfer Tank System Totals to the indicated columns on the correct Inventory Sheet for this Tank System.

MANIFOLDED TANK SYSTEM RECORDING SHEET

Day	Date	Meter Recordings in Gallons	Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank System Totals	Transfer to Inventory Sheet
21		A. Opening Stick (gals) (Yesterday's Line E)										
		B. Deliveries (gals)										Col 2
		C. Total of Fuel in Tank (A + B)										Col 3
		D. Closing Stick (inches)										Col 4
		E. Closing Stick (gals)										Col 5
		F. Fuel Gone from Tank (gals) (C - E)										Col 6
22		A. Opening Stick (gals) (Yesterday's Line E)										Col 7
		B. Deliveries (gals)										Col 2
		C. Total of Fuel in Tank (A + B)										Col 3
		D. Closing Stick (inches)										Col 4
		E. Closing Stick (gals)										Col 5
		F. Fuel Gone from Tank (gals) (C - E)										Col 6
23		A. Opening Stick (gals) (Yesterday's Line E)										Col 7
		B. Deliveries (gals)										Col 2
		C. Total of Fuel in Tank (A + B)										Col 3
		D. Closing Stick (inches)										Col 4
		E. Closing Stick (gals)										Col 5
		F. Fuel Gone from Tank (gals) (C - E)										Col 6
24		A. Opening Stick (gals) (Yesterday's Line E)										Col 7
		B. Deliveries (gals)										Col 2
		C. Total of Fuel in Tank (A + B)										Col 3
		D. Closing Stick (inches)										Col 4
		E. Closing Stick (gals)										Col 5
		F. Fuel Gone from Tank (gals) (C - E)										Col 6
												Col 7

*Transfer Tank System Totals to the indicated columns on the correct Inventory Sheet for this Tank System.

MANIFOLDED TANK SYSTEM RECORDING SHEET

Day	Date	Meter Recordings in Gallons	Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank System Totals	Transfer to Inventory Sheet
25		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
26		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
27		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
28		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7

*Transfer Tank System Totals to the indicated columns on the correct Inventory Sheet for this Tank System.

MANIFOLDED TANK SYSTEM RECORDING SHEET

Day	Date	Meter Recordings in Gallons	Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank System Totals	Transfer to Inventory Sheet
29		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7
30		A. Opening Stick (gals) (Yesterday's Line E)										Col 2
		B. Deliveries (gals)										Col 3
		C. Total of Fuel in Tank (A + B)										Col 4
		D. Closing Stick (inches)										Col 5
		E. Closing Stick (gals)										Col 6
		F. Fuel Gone from Tank (gals) (C - E)										Col 7

*Transfer Tank System Totals to the indicated columns on the correct Inventory Sheet for this Tank System.

INSTRUCTIONS FOR COMPLETING
INVENTORY SHEET FOR TANKS WITHOUT METERED DISPENSING PUMPS

The Inventory Sheet for Tanks Without Metered Dispensing Pumps is the only sheet to be used with tanks having unmetered dispensing pumps. Without metered dispensing pumps, it is difficult to use inventory records to monitor for fuel losses, because the quantities of fuel being pumped from that tank are unknown. As a result, inventory calculations must be based on stick readings alone. You will need an accurate dipstick and the correct inches-to-gallons conversion chart for your unmetered tank.

You will need to make a series of 30 opening and closing dipstick readings of your unmetered tank. There should be one or more days between each of the 30 readings. Figure 2, below, shows two plans for taking the 30 readings.

Figure 2

Inventory Readings Plans for Unmetered Tanks

PLAN A: Immediately before each withdrawal or delivery of fuel, enter the date and opening stick readings for the tank on the inventory sheet. Immediately after the withdrawal or delivery make and record the closing stick reading on the inventory sheet. Deliveries should be entered from the delivery receipt you receive from the fuel truck driver. (All deliveries will be made when the facility is "open," since the delivery will be occur between the opening and closing stick readings.)

PLAN B: At the beginning of each operating day (before any withdrawals of fuel) record the date and opening stick reading for the day. At the end of the day (after all withdrawals of fuel) record the closing stick readings. If a delivery occurs while "closed" (after the closing dipstick reading was taken) record the quantity delivered (from the receipt) on the line for the following day and circle the code (2) for "closed." If a delivery occurs while your facility is open, record the quantity delivered on the line for the day the delivery occurred and circle the code (1) for "open." NOTE: It is not necessary to have withdrawals or deliveries during an operating day in order to fill in an inventory line, as long as you make and record both opening and closing stick readings.

If your tank is used very infrequently (once a day or less) you may wish to follow Plan A. Plan A requires that you record dipstick readings on the tank each time you use the tank. If the tank is used more than once a day, you should follow Plan B. Plan B requires that you record dipstick readings at the opening and closing of each operating (business) day.

The step-by-step instructions for recording inventory on the "Inventory Sheet for Tanks Without Metered Dispensing Pumps" are:

- In Column 1, record the date that the inventory reading will be made (day and month).
- In Column 2, record the opening dipstick reading, in inches (to the nearest quarter inch).
- In Column 3, record the opening dipstick reading, in gallons (as calculated from your inches-to-gallons conversion chart for this tank).
- In Column 4, record the closing dipstick reading, in inches (to the nearest quarter inch).
- In Column 5, record the closing dipstick reading, in gallons (as calculated from your inches-to-gallons conversion chart for this tank).
- In Column 6, record the amount delivered to the tank since your closing reading on the line above. (The "Gallons Delivered" should be taken from the receipt provided by the fuel delivery truck driver.)
- Finally, in Column 7, please indicate whether the fuel delivery was made before the opening stick reading on this line (i.e., when the facility was closed) or during the time between the opening and closing stick readings (i.e., when the facility was open).

INVENTORY SHEET FOR TANKS WITHOUT METERED DISPENSING PUMPS

Tank Number: ____________________

Type of Fuel: ____________________

Size of Tank: ____________________

Year Installed: ____________________

____
(Name of Facility)

____
(Street Address)

____
(City/Town) (State) (Zip)

		Dipstick* Inventory					
	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Day	Date	Opening Dipstick* Reading (inches)	Opening Dipstick* Reading (gallons)	Closing Dipstick* Inventory (inches)	Closing Dipstick* Inventory (gallons)	Deliveries (in gallons)	Was delivery made while open or closed? (Circle one) Open Closed
1							1 2
2							1 2
3							1 2
4							1 2
5							1 2
6							1 2
7							1 2
8							1 2
9							1 2
10							1 2
11							1 2
12							1 2
13							1 2
14							1 2
15							1 2
16							1 2
17							1 2
18							1 2
19							1 2
20							1 2
21							1 2
22							1 2
23							1 2
24							1 2
25							1 2
26							1 2
27							1 2
28							1 2
29							1 2
30							1 2

*If tank has remote gauge, check here ☐ and use remote gauge readings instead of stick readings.

REPORTING RESPONSIBILITIES OF TANK OWNERS AND OPERATORS

On November 8, 1984, President Reagan signed the Hazardous and Solid Waste Amendments of 1984, amending the Resource Conservation and Recovery Act (RCRA). Section 9005(a) of RCRA, as amended, states:

> "FURNISHING INFORMATION--For the purposes of developing or assisting in the development of any regulation, conducting any study, or enforcing the provisions of this subtitle [Subtitle I of Title VI, 'Regulation of Underground Storage Tanks], any owner or operator of an underground storage tank . . . shall upon request of any officer, employee or representative of the Environmental Protection Agency duly designated by the Administrator, . . . furnish information relating to such tanks, their associated equipment, their contents, conduct monitoring or testing, and permit such officer at all reasonable times to have access to, and copy all records relative to such tanks [underline added for emphasis]. For the purposes of developing or assisting in the development of any regulation, conducting any study, or enforcing the provisions of this subtitle, such officers, employees or representatives are authorized --
>
> "(1) to enter at reasonable times any establishment or other place where an underground storage tank is located;
>
> "(2) to inspect and obtain samples from any person of any regulated substance contained in such tank; and
>
> "(3) to conduct monitoring or testing of the tanks, associated equipment, contents, or surrounding soils, air, surface water or ground water.
>
> Each such inspection shall be commenced and completed with reasonable promptness.

Section 9006, "FEDERAL ENFORCEMENT," gives EPA the authority to issue compliance orders and to commence civil actions for noncompliance with the requirements of Section 9005. Section 90006(a)(3) authorizes EPA to seek civil penalties for violation of such an order, not to exceed $25,000 per day of continued noncompliance.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
PESTICIDES AND TOXIC SUBSTANCES

Dear Establishment Owner/Operator:

If there are no underground motor fuel storage tanks located at your establishment, please sign the certification statement below indicating this and return in the postage paid envelope provided. If there are abandoned or out of service underground motor fuel storage tanks at this establishment you should not sign this statement. If the interviewer calls after you have mailed the signed statement, inform him/her that you have done so.

Sincerely,

Martin P. Halper, Director
Exposure Evaluation Division

Establishment Name:
Establishment Address:

Establishment Telephone:

CERTIFICATION STATEMENT FOR ESTABLISHMENTS WITHOUT TANKS

THE OWNER OR THE OPERATOR OF THE FACILITY, OR HIS AUTHORIZED REPRESENTATIVE, SHOULD SIGN AND DATE THE CERTIFICATION WHERE INDICATED. THE PRINTED OR TYPED NAME OF THE PERSON SIGN-THE CERTIFICATION SHOULD ALSO BE INCLUDED WHERE INDICATED.

CERTITIFICATION:

I hereby certify that there are no underground motor fuel storage tanks at the establishment at the above address. I am aware that there are significant penalties for submitting false information, including the possibility of a fine.

Print or type name
Signature
Date signed

OMB No.: 2070-0037
Expires: December 31, 1985

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

UNDERGROUND STORAGE TANK SURVEY

ESTABLISHMENT OPERATOR'S QUESTIONNAIRE

Conducted by:

WESTAT
An Employee-Owned Research Corporation
1650 Research Blvd • Rockville MD 20850 • 301 251-1500

A. SCREENING INFORMATION

01

A1. What type of establishment is this? [CIRCLE ONLY ONE CODE]

a. FARM OR RANCH . . . . 01 /60-61
b. GASOLINE SERVICE STATION.

[PLEASE SELECT ONE OF THE FOLLOWING SUBCATEGORIES]: /62-63

b1. FULL SERVICE STATION (WHERE MOTOR VEHICLE REPAIR WORK IS DONE) 02
b2. LARGE, HIGH VOLUME STATION 03
b3. CONVENIENCE STORE. 04
b4. SELF SERVICE GASOLINE STATION. 05
b5. OTHER [PLEASE DESCRIBE] ________________
________________________________ 06 /64-65

c. MILITARY FACILITY 07
d. FEDERAL AGENCY OR OFFICE. 08
e. STATE AGENCY OR OFFICE. 09
f. LOCAL GOVERNMENT AGENCY OR OFFICE 10
g. MARINA. 11
h. TAXI SERVICE OR COMPANY 12
i. BUS FLEET FACILITY. 13
j. TRUCK FLEET FACILITY. 14
k. AIRPORT OR AIRFIELD 15
l. RAILROAD DEPOT. 16
m. OTHER BUSINESS [PLEASE SPECIFY YOUR ESTABLISHMENT'S PRIMARY PRODUCT OR SERVICE]: ________________ 17 /66-67
____

n. BULK FUEL PLANT OR TERMINAL . . . . 18 →
o. PRIVATE RESIDENCE THAT IS NOT ASSOCIATED WITH A FARM OR RANCH. . . . . 19 →
p. OTHER [SPECIFY]: ________________ 20

PLEASE DO NOT COMPLETE THE REST OF THIS QUESTIONNAIRE! PLEASE CALL WESTAT AT THE 800-638-8985 (TOLL FREE NUMBER) AND ASK FOR THE "EPA SPECIALIST."

/68-69

BOX A1

IF A1 = MILITARY, FEDERAL, STATE OR LOCAL AGENCY (CODES 07, 08, 09 OR 10), CHECK HERE ☐ AND SKIP TO A6. OTHERWISE, GO ON TO A2. /70

A2. Is this establishment owned and/or operated by a major petroleum company? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /71

A3. What is the name and address of the owner of this establishment?

Owner's Name ____________________________________

Owner's Address ____________________________________

____

A4. What is the name and address of the operator of this establishment?

Operator's Name: ____________________________________

Operator's Address: ____________________________________

____

A5. What is the motor fuel that is stored at this establishment used for: retail sales, wholesale sales, or for use by the establishment itself? [CIRCLE ONE CODE FOR EACH ITEM]

	YES	NO	
a. RETAIL SALES	1	2	/72
b. WHOLESALE SALES.	1	2	/73
c. USE BY THIS ESTABLISHMENT.	1	2	/74
d. OTHER [SPECIFY]: __________________	1	2	/75
________________________________			/76-77

A6. Does this establishment have any underground storage tanks that are used to store motor fuel? [CIRCLE ONLY ONE CODE] /78

YES [GO ON TO A7]. . 1

NO . . . . 2 →

PLEASE DO NOT COMPLETE THE REST OF THIS QUESTIONNAIRE! PLEASE CALL WESTAT AT 800-638-8985 (TOLL FREE NUMBER) AND ASK FOR THE "EPA SPECIALIST."

A7. How many underground storage tanks currently in use are used to store motor fuels?

NUMBER OF TANKS: ____________________ /79-81

A8. Does this establishment have any underground storage tanks that are used to store used or waste oil? [CIRCLE ONLY ONE CODE]

YES [GO ON TO A9]. . . . . 1 /82

NO [SKIP TO A11] 2

A9. How many underground storage tanks currently in use are used to store used or waste oil?

NUMBER OF USED OR WASTE OIL UNDERGROUND TANKS: ________________________ /83-85

A10. What (is/are) the capacity/ies of your used or waste oil tank(s)? [ENTER CAPACITIES IN GALLONS]

a. Capacity of used or waste oil tank #1 . . . . ____________ gallons /86-91
b. Capacity of used or waste oil tank #2 . . . . ____________ gallons /92-97
c. Capacity of used or waste oil tank #3 . . . . ____________ gallons /98-103

A11. Please fill out one Tank Description Sheet for each underground storage tank that this facility uses to store motor fuel. There are six (6) Tank Description Sheets bound into this booklet. If there are more than six underground storage tanks at this establishment, either photocopy as many additional sheets as are required to describe all the tanks, or write the answers to the questions for each extra tank on a plain sheet of paper.

TANK DESCRIPTION SHEET INSTRUCTIONS

1. Use the space on the next page to draw a map of the underground tank area at your establishment. On the map, show the location of each tank, the pumps/dispensers for each tank, and any buildings and features associated with the tanks (such as a garage, driveway, or wall). See the example map below showing a gasoline service station with three tanks and two pump islands.

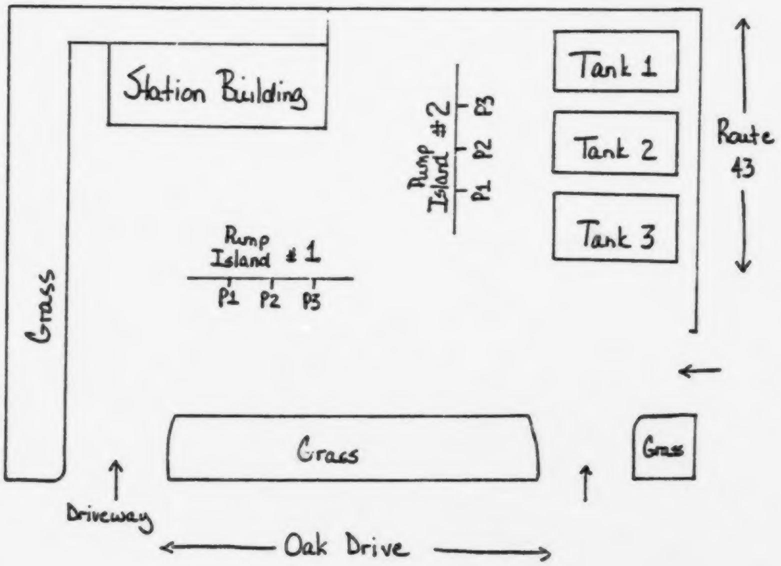
2. Assign a number to each underground storage tank at this establishment, and write that number on the tank in your map. (See example below.) Also write the tank number in the upper lefthand corner of the Tank Description Sheet for that tank.

3. It is only necessary to fill out Tank Description Sheets for tanks that are on site at this establishment. Do not fill out Tank Description Sheets for any tanks that this establishment may use, own or maintain off site.

4. If another establishment uses or maintains an underground storage tank on your establishment's site/property, you should complete a Tank Description Sheet for that tank and include it on your map.

5. Large establishments with more than one tank area may find it easier to draw individual maps of each tank area, rather than drawing one large map.

Example Map



TANK NUMBER: ____________

TANK DESCRIPTION SHEET

T1. What is the capacity of this tank? (That is, what is the maximum number of gallons of fuel it can hold?) [ENTER CAPACITY IN GALLONS]

TANK DESIGN CAPACITY: ____________ gallons
16-21

T2. What is the average amount of fuel in this tank just before a delivery? (That is, what is the low point of the product level?) [ENTER QUANTITY IN GALLONS]

AVERAGE CONTENTS BEFORE DELIVERY: ________ gallons
22-27

T3. What is the average amount of fuel delivered to this tank? [ENTER QUANTITY IN GALLONS]

AVERAGE SIZE OF DELIVERY: ____________ gallons
28-33

T4. What is the maximum number of gallons of fuel that has ever been stored in this tank? (That is, how full have you actually filled it?) [ENTER QUANTITY IN GALLONS]

LARGEST QUANTITY HELD IN TANK: __________ gallons
/34-39

T5. In what year was this tank installed?

YEAR OF INSTALLATION: ____________
/40-43

T6. Was this tank new or used when it was installed? [CIRCLE ONLY ONE CODE]

NEW [SKIP TO T8]. 1
USED [GO ON TO T7]. 2
DON'T KNOW [SKIP TO T8] . . . 8
/44

T7. How old was this tank when it was installed?

AGE IN YEARS: ____________
/45-47

T8. Is this tank scheduled for replacement or repair within the next 12 months? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2
/48

T9. Has this tank ever been repaired? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T10]. 1
NO [SKIP TO T12]. 2
DON'T KNOW [SKIP TO T12]. . . 8
/49

T10. In what year was this tank last repaired?

YEAR LAST REPAIRED: ____________
/50-53

T11. What types of repairs were done to this tank?

REPAIRS: ____________
/54-55
____
____
/56-57

T12. Which of the following fuel types were stored in this tank during the past 12 months? [CIRCLE ONE CODE FOR EACH FUEL TYPE]

		YES	NO
a.	Leaded gasoline	1	2
b.	Unleaded gasoline	1	2
c.	Diesel fuel	1	2
d.	Aviation fuel	1	2
e.	Gasohol	1	2
f.	Other [SPECIFY]: __________	1	2

____
/58-65

T13. Does this tank have a pump?

YES [GO ON TO T14]. 1
NO [SKIP TO T18]. 2
/66

T14. How many pumps are connected to this tank?

NUMBER OF PUMPS ____________
67-69

T15. Does this tank have a "suction" or a "submerged" (pressure) pump delivery system? [CIRCLE ONLY ONE CODE]

SUCTION 01
SUBMERGED 02
OTHER [SPECIFY]: __________ 03
____
/70-71

T16. How many dispensers (nozzles) are connected to this tank?

NUMBER OF NOZZLES: ____________
/72-74

T17. Do the product dispensers (nozzles) for this tank have meters to measure the total quantity of product that has been pumped from the tank? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2
/75

T18. Is this tank attached to another tank by pipes or lines? [CIRCLE ONLY ONE CODE]

YES [PLEASE SPECIFY THE TANK NUMBER(S) OF THE CONNECTED TANK(S)] ____ /76
____________ 1
NO. 2
/77-78

T19. How is this tank situated in relation to the water table? Is it: [CIRCLE ONLY ONE CODE]

Completely above the water table. . . . 01
Partially above and partially below the water table. 02
Or, is the top surface of the tank completely below the water table . . . 03
Other [SPECIFY]: ____________ 04
/79-80

T20. Does this tank have a manway or other means of being entered for internal inspection? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T21]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8
/81

T21. Has the interior of the tank ever been inspected? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T22]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8
/82

T22. When was the most recent internal inspection of this tank?

MOST RECENT INSPECTION: ____________
/83-86

T23. Has the tank ever been tested for leaks after it was placed in service? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T24]. 1
NO [SKIP TO T26]. 2
DON'T KNOW [SKIP TO T26]. . . 8
/87

T24. What test method was used to test the tank? (Please give the brand name of the test, if known, and describe the test procedure. If more than one method was used, describe all methods used.)

METHOD(S): ____________
____
/88-89
____
____
/90-91

03

TANK DESCRIPTION SHEET (Continued)

TANK
NUMBER: ____________

T25. In what year was the tank last tested by this/these methods?

YEAR LAST TESTED: ______________________ /16-19

T26. Of what material is this tank constructed? [CIRCLE ONLY ONE CODE]

FIBERGLASS-REINFORCED PLASTIC . 01
STEEL 02
OTHER [SPECIFY]: ____________ 03

______________________ /20-21

T27. Is the inside of this tank lined? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T28]. 1
NO [SKIP TO T30]. 2
DON'T KNOW [SKIP TO T30]. . . 8 /22

T28. In what year was the lining installed?

YEAR LINED: ______________ /23-26

T29. Of what material is the liner constructed? [CIRCLE ONLY ONE CODE]

EPOXY-BASED RESINS. 01
FIBERGLASS REINFORCED PLASTIC . . . 02
ISOPHTHALIC POLYESTER-BASED RESINS. 03
POLYURETHANE-BASED RESINS 04
OTHER [SPECIFY]: ______________ 05

______________________ /27-28

T30. Is the outside of this tank coated? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T31]. 1
NO [SKIP TO T32]. 2
DON'T KNOW [SKIP TO T32]. . . 8 /29

T31. Of what material is the coating constructed? [CIRCLE ONLY ONE CODE]

FIBERGLASS/EPOXY. 01
ASPHALTIC MATERIAL. 02
URETHANE. 03
COAL TAR EPOXY. 04
OTHER [SPECIFY]: __________ 05

______________________ /30-31

T32. Is there secondary containment for this tank? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T33] 1
NO [SKIP TO T34] 2
DON'T KNOW [SKIP TO T34] . . . . . . 8 /32

T33. Is this secondary containment a:

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall tank?. 04
or something else [SPECIFY]: _______ 05

______________________ /33-34

T34. Is there secondary containment for any equipment that is attached to this tank (such as pipes, pumps, valves, etc.)? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T35] 1
NO [SKIP TO T36] 2
DON'T KNOW [SKIP TO T36] . . . . . . 8 /35

T35. Is this secondary containment a:

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall piping?. 04
or something else [SPECIFY]: _______ 05

____

T36. What is the name of the company that installed the tank?

INSTALLER: ______________________

T37. Is there a paved surface over the tank? /38-39

YES [GO ON TO T38] 1
NO [SKIP TO T40] . . . . 2 /40

T38. Is this pavement:

asphalt?. 01
concrete? 02
gravel? 03
other [SPECIFY]: __________ 04

______________________ /41-42

T39. How thick is the pavement?

THICKNESS: ______________ /43-45

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ________ /46-47

______________________ 03

T40. What is the distance from the surface to the top of the tank?

DISTANCE TO SURFACE: __________ /48-50

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ________ /51-52

______________________ 03

T41. Does this tank have any of the following kinds of protection against corrosion? [CIRCLE ONLY ONE CODE FOR EACH ITEM]

		Yes	No	
a.	Passive cathodic protection (using sacrificial anodes)? . .	1	2	/53
b.	Cathodic protection using impressed current?.	1	2	/54
c.	Other [SPECIFY]: ____________	1	2	/55

____

T42. Has this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE] /56-57

YES [GO ON TO T43] 1
NO [SKIP TO T44] 2
DON'T KNOW [SKIP TO T44] . . . 8 /58

T43. How was the leak detected and/or verified? [CIRCLE ALL THAT APPLY]

INVENTORY RECONCILIATION . . . 01 /59-60
ENVIRONMENTAL MONITORING . . . 02 /61-62
FACILITY INSPECTION. . . . . . 03 /63-64
TANK TESTING . . . . 04 /65-66
OTHER [SPECIFY]: __________

______________________ 05 /67-68

T44. Have the lines (piping) for this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE]

YES. 1
NO 2 69
DON'T KNOW 8

02

TANK DESCRIPTION SHEET

TANK NUMBER: ____________

T1. What is the capacity of this tank? That is, what is the maximum number of gallons of fuel it can hold? [ENTER CAPACITY IN GALLONS]

TANK DESIGN CAPACITY: ____________ gallons /16-21

T2. What is the average amount of fuel in this tank just before a delivery? That is, what is the low point of the product level? [ENTER QUANTITY IN GALLONS]

AVERAGE CONTENTS BEFORE DELIVERY: ________ gallons 22-27

T3. What is the average amount of fuel delivered to this tank? [ENTER QUANTITY IN GALLONS]

AVERAGE SIZE OF DELIVERY: ____________ gallons 28-33

T4. What is the maximum number of gallons of fuel that has ever been stored in this tank? (That is, how full have you actually filled it?) [ENTER QUANTITY IN GALLONS]

LARGEST QUANTITY HELD IN TANK: __________ gallons 34-39

T5. In what year was this tank installed?

YEAR OF INSTALLATION: ____________ /40-43

T6. Was this tank new or used when it was installed? [CIRCLE ONLY ONE CODE]

NEW [SKIP TO T8]. 1
USED [GO ON TO T7]. 2
DON'T KNOW [SKIP TO T8] . . . 8

/44

T7. How old was this tank when it was installed?

AGE IN YEARS: ____________ /45-47

T8. Is this tank scheduled for replacement or repair within the next 12 months? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2

/48

T9. Has this tank ever been repaired? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T10]. 1
NO [SKIP TO T12]. 2
DON'T KNOW [SKIP TO T12]. . . 8

/49

T10. In what year was this tank last repaired?

YEAR LAST REPAIRED: ____________ /50-53

T11. What types of repairs were done to this tank?

REPAIRS: ____________ /54-55

____

____________ /56-57

T12. Which of the following fuel types were stored in this tank during the past 12 months? [CIRCLE ONE CODE FOR EACH FUEL TYPE]

	YES	NO
a. Leaded gasoline	1	2
b. Unleaded gasoline	1	2
c. Diesel fuel	1	2
d. Aviation fuel	1	2
e. Gasohol	1	2
f. Other [SPECIFY]: ____________	1	2

____________ /58-65

T13. Does this tank have a pump?

YES [GO ON TO T14]. 1
NO [SKIP TO T18]. 2

/66

T14. How many pumps are connected to this tank?

NUMBER OF PUMPS ____________ /67-69

T15. Does this tank have a "suction" or a "submerged" (pressure) pump delivery system? [CIRCLE ONLY ONE CODE]

SUCTION 01
SUBMERGED 02
OTHER [SPECIFY]: __________ 03

____________ /70-71

T16. How many dispensers (nozzles) are connected to this tank?

NUMBER OF NOZZLES: ____________ /72-74

T17. Do the product dispensers (nozzles) for this tank have meters to measure the total quantity of product that has been pumped from the tank? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2

/75

T18. Is this tank attached to another tank by pipes or lines? [CIRCLE ONLY ONE CODE]

YES [PLEASE SPECIFY THE TANK NUMBER(S) OF THE CONNECTED TANK(S)] ____ /76

____________ 1
NO. 2

/77-78

T19. How is this tank situated in relation to the water table? Is it: [CIRCLE ONLY ONE CODE]

Completely above the water table. . . . 01
Partially above and partially below the water table. 02
Or, is the top surface of the tank completely below the water table . . . 03
Other [SPECIFY]: ____________ 04

/79-80

T20. Does this tank have a manway or other means of being entered for internal inspection? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T21]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8

/81

T21. Has the interior of the tank ever been inspected? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T22]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8

/82

T22. When was the most recent internal inspection of this tank?

MOST RECENT INSPECTION: ____________ /83-86

T23. Has the tank ever been tested for leaks after it was placed in service? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T24]. 1
NO [SKIP TO T26]. 2
DON'T KNOW [SKIP TO T26]. . . 8

/87

T24. What test method was used to test the tank? (Please give the brand name of the test, if known, and describe the test procedure. If more than one method was used, describe all methods used.)

METHOD(S): ____________

____________ /88-89

____

____________ /90-91

33

TANK DESCRIPTION SHEET (Continued)

TANK NUMBER: ____________

T25. In what year was the tank last tested by this/these methods?

YEAR LAST TESTED: ____________ /16-19

T26. Of what material is this tank constructed? [CIRCLE ONLY ONE CODE]

FIBERGLASS-REINFORCED PLASTIC . 01
STEEL 02
OTHER [SPECIFY]: ____________ 03

____________ /20-21

T27. Is the inside of this tank lined? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T28]. 1
NO [SKIP TO T30]. 2
DON'T KNOW [SKIP TO T30]. . . 8

T28. In what year was the lining installed? /22

YEAR LINED: ____________

T29. Of what material is the liner constructed? [CIRCLE ONLY ONE CODE] /23-26

EPOXY-BASED RESINS. 01
FIBERGLASS REINFORCED PLASTIC . . . 02
ISOPHTHALIC POLYESTER-BASED RESINS. 03
POLYURETHANE-BASED RESINS 04
OTHER [SPECIFY]: ____________ 05

____

T30. Is the outside of this tank coated? [CIRCLE ONLY ONE CODE] /27-28

YES [GO ON TO T31]. 1
NO [SKIP TO T32]. 2
DON'T KNOW [SKIP TO T32]. . . 8

T31. Of what material is the coating constructed? [CIRCLE ONLY ONE CODE] /29

FIBERGLASS EPOXY. 01
ASPHALTIC MATERIAL. 02
URETHANE. 03
COAL TAR EPOXY. 04
OTHER [SPECIFY]: ____________ 05

____

T32. Is there secondary containment for this tank? [CIRCLE ONLY ONE CODE] /30-31

YES [GO ON TO T33] 1
NO [SKIP TO T34] 2
DON'T KNOW [SKIP TO T34] 8

33. Is this secondary containment a: /32

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall tank?. 04
or something else [SPECIFY]: ______ 05

____________ /33-34

T34. Is there secondary containment for any equipment that is attached to this tank (such as pipes, pumps, valves, etc.)? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T35] 1
NO [SKIP TO T36] 2
DON'T KNOW [SKIP TO T36] 8

T35. Is this secondary containment a: /35

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall piping?. 04
or something else [SPECIFY]: ______ 05

____________ /36-37

T36. What is the name of the company that installed the tank?

INSTALLER: ____________

T37. Is there a paved surface over the tank? /38-39

YES [GO ON TO T38] 1
NO [SKIP TO T40] 2

T38. Is this pavement: 40

asphalt?. 01
concrete? 02
gravel? 03
other [SPECIFY]: ____________ 04

____

T39. How thick is the pavement? /41-42

THICKNESS: ____________ /43-45

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ________ /46-47

____________ 03

T40. What is the distance from the surface to the top of the tank?

DISTANCE TO SURFACE: ____________ /48-50

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ________ /51-52

____________ 03

T41. Does this tank have any of the following kinds of protection against corrosion? [CIRCLE ONLY ONE CODE FOR EACH ITEM]

		Yes	No	
a.	Passive cathodic protection (using sacrificial anodes)? . .	1	2	/53
b.	Cathodic protection using impressed current?.	1	2	/54
c.	Other [SPECIFY]: ____________	1	2	/55

____

T42. Has this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE] /56-57

YES [GO ON TO T43] 1
NO [SKIP TO T44] 2
DON'T KNOW [SKIP TO T44] . . . 8

T43. How was the leak detected and/or verified? [CIRCLE ALL THAT APPLY] /58

INVENTORY RECONCILIATION . . . 01 /59-60
ENVIRONMENTAL MONITORING . . . 02 /61-62
FACILITY INSPECTION. . . . . . 03 /63-64
TANK TESTING . . . . 04 /65-66
OTHER [SPECIFY]: ____________

____________ 05 /67-68

T44. Have the lines (piping) for this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE]

YES. 1
NO 2
DON'T KNOW . . . . 8 /69

02

TANK DESCRIPTION SHEET

TANK NUMBER: ____________

T1. What is the capacity of this tank? (That is, what is the maximum number of gallons of fuel it can hold?) [ENTER CAPACITY IN GALLONS]

TANK DESIGN CAPACITY: ________________ gallons
/16-21

T2. What is the average amount of fuel in this tank just before a delivery? (That is, what is the low point of the product level?) [ENTER QUANTITY IN GALLONS]

AVERAGE CONTENTS BEFORE DELIVERY: ________ gallons
/22-27

T3. What is the average amount of fuel delivered to this tank? [ENTER QUANTITY IN GALLONS]

AVERAGE SIZE OF DELIVERY: ________________ gallons
/28-33

T4. What is the maximum number of gallons of fuel that has ever been stored in this tank? (That is, how full have you actually filled it?) [ENTER QUANTITY IN GALLONS]

LARGEST QUANTITY HELD IN TANK: __________ gallons
/34-39

T5. In what year was this tank installed?

YEAR OF INSTALLATION: ____________________
/40-43

T6. Was this tank new or used when it was installed? [CIRCLE ONLY ONE CODE]

NEW [SKIP TO T8]. 1
USED [GO ON TO T7]. 2
DON'T KNOW [SKIP TO T8] . . . 8
/44

T7. How old was this tank when it was installed?

AGE IN YEARS: ____________________
/45-47

T8. Is this tank scheduled for replacement or repair within the next 12 months? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2
/48

T9. Has this tank ever been repaired? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T10]. 1
NO [SKIP TO T12]. 2
DON'T KNOW [SKIP TO T12]. . . 8
/49

T10. In what year was this tank last repaired?

YEAR LAST REPAIRED: ____________________
/50-53

T11. What types of repairs were done to this tank?

REPAIRS: ______________________________
/54-55
____
____
/56-57

T12. Which of the following fuel types were stored in this tank during the past 12 months? [CIRCLE ONE CODE FOR EACH FUEL TYPE]

	YES	NO
a. Leaded gasoline	1	2
b. Unleaded gasoline	1	2
c. Diesel fuel	1	2
d. Aviation fuel	1	2
e. Gasohol	1	2
f. Other [SPECIFY]: __________	1	2

____
/58-65

T13. Does this tank have a pump?

YES [GO ON TO T14]. 1
NO [SKIP TO T18]. 2
/66

T14. How many pumps are connected to this tank?

NUMBER OF PUMPS ____________
/67-69

T15. Does this tank have a "suction" or a "submerged" (pressure) pump delivery system? [CIRCLE ONLY ONE CODE]

SUCTION 01
SUBMERGED 02
OTHER [SPECIFY]: ___________ 03

____
/70-71

T16. How many dispensers (nozzles) are connected to this tank?

NUMBER OF NOZZLES: ________________________
/72-74

T17. Do the product dispensers (nozzles) for this tank have meters to measure the total quantity of product that has been pumped from the tank? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2
/75

T18. Is this tank attached to another tank by pipes or lines? [CIRCLE ONLY ONE CODE]

YES [PLEASE SPECIFY THE TANK NUMBER(S) OF THE CONNECTED TANK(S)] ____ /76

________________________ 1
NO. 2
/77-78

T19. How is this tank situated in relation to the water table? Is it: [CIRCLE ONLY ONE CODE]

Completely above the water table. . . . 01
Partially above and partially below the water table. 02
Or, is the top surface of the tank completely below the water table . . . 03
Other [SPECIFY]: __________________ 04
/79-80

T20. Does this tank have a manway or other means of being entered for internal inspection? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T21]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8
/81

T21. Has the interior of the tank ever been inspected? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T22]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8
/82

T22. When was the most recent internal inspection of this tank?

MOST RECENT INSPECTION: ____________________
/83-86

T23. Has the tank ever been tested for leaks after it was placed in service? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T24]. 1
NO [SKIP TO T26]. 2
DON'T KNOW [SKIP TO T26]. . . 8
/87

T24. What test method was used to test the tank? (Please give the brand name of the test, if known, and describe the test procedure. If more than one method was used, describe all methods used.)

METHOD(S): ______________________________
____
/88-89
____
____
/90-91

03

TANK DESCRIPTION SHEET (Continued)

TANK NUMBER: ______

T25. In what year was the tank last tested by this/these methods?

YEAR LAST TESTED: ______ /16-19

T26. Of what material is this tank constructed? [CIRCLE ONLY ONE CODE]

FIBERGLASS-REINFORCED PLASTIC . 01
STEEL 02
OTHER [SPECIFY]: ______ 03

______ /20-21

T27. Is the inside of this tank lined? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T28]. 1
NO [SKIP TO T30]. 2
DON'T KNOW [SKIP TO T30]. . . 8

T28. In what year was the lining installed? /22

YEAR LINED: ______

T29. Of what material is the liner constructed? [CIRCLE ONLY ONE CODE] /23-26

EPOXY-BASED RESINS. 01
FIBERGLASS REINFORCED PLASTIC . . . 02
ISOPHTHALIC POLYESTER-BASED RESINS. 03
POLYURETHANE-BASED RESINS 04
OTHER [SPECIFY]: ______ 05

______

T30. Is the outside of this tank coated? [CIRCLE ONLY ONE CODE] /27-28

YES [GO ON TO T31]. 1
NO [SKIP TO T32]. 2
DON'T KNOW [SKIP TO T32]. . . 8

T31. Of what material is the coating constructed? [CIRCLE ONLY ONE CODE] /29

FIBERGLASS/EPOXY. 01
ASPHALTIC MATERIAL. 02
URETHANE. 03
COAL TAR EPOXY. 04
OTHER [SPECIFY]: ______ 05

______

T32. Is there secondary containment for this tank? [CIRCLE ONLY ONE CODE] /30-31

YES [GO ON TO T33] 1
NO [SKIP TO T34] 2
DON'T KNOW [SKIP TO T34] 8

T33. Is this secondary containment a: /32

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall tank?. 04
or something else [SPECIFY]: ______ 05

______

T34. Is there secondary containment for any equipment that is attached to this tank (such as pipes, pumps, valves, etc.)? [CIRCLE ONLY ONE CODE] /33-34

YES [GO ON TO T35] 1
NO [SKIP TO T36] 2
DON'T KNOW [SKIP TO T36] 8

T35. Is this secondary containment a: /35

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall piping?. 04
or something else [SPECIFY]: ______ 05

______ /36-37

T36. What is the name of the company that installed the tank?

INSTALLER: ______ /38-39

T37. Is there a paved surface over the tank?

YES [GO ON TO T38] 1
NO [SKIP TO T40] 2

T38. Is this pavement: /40

asphalt?. 01
concrete? 02
gravel? 03
other [SPECIFY]: ______ 04

______

T39. How thick is the pavement? /41-42

THICKNESS: ______ /43-45

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ______ /46-47

______ 03

T40. What is the distance from the surface to the top of the tank?

DISTANCE TO SURFACE: ______ /48-50

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ______ /51-52

______ 03

T41. Does this tank have any of the following kinds of protection against corrosion? [CIRCLE ONLY ONE CODE FOR EACH ITEM]

		Yes	No	
a.	Passive cathodic protection (using sacrificial anodes)? . .	1	2	/53
b.	Cathodic protection using impressed current?.	1	2	/54
c.	Other [SPECIFY]: ______	1	2	/55

______

T42. Has this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE] /56-57

YES [GO ON TO T43] 1
NO [SKIP TO T44] 2
DON'T KNOW [SKIP TO T44] . . . 8

T43. How was the leak detected and/or verified? [CIRCLE ALL THAT APPLY] /58

INVENTORY RECONCILIATION . . . 01 /59-60
ENVIRONMENTAL MONITORING . . . 02 /61-62
FACILITY INSPECTION. . . . . . 03 /63-64
TANK TESTING . . . . 04 /65-66
OTHER [SPECIFY]: ______

______ 05 /67-68

T44. Have the lines (piping) for this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE]

YES. 1
NO 2
DON'T KNOW . . . . 8 /69

02

TANK DESCRIPTION SHEET

TANK NUMBER: ____________

T1. What is the capacity of this tank? (That is, what is the maximum number of gallons of fuel it can hold?) [ENTER CAPACITY IN GALLONS]

TANK DESIGN CAPACITY: ____________ gallons /16-21

T2. What is the average amount of fuel in this tank just before a delivery? (That is, what is the low point of the product level?) [ENTER QUANTITY IN GALLONS]

AVERAGE CONTENTS BEFORE DELIVERY: ________ gallons /22-27

T3. What is the average amount of fuel delivered to this tank? [ENTER QUANTITY IN GALLONS]

AVERAGE SIZE OF DELIVERY: ____________ gallons /28-33

T4. What is the maximum number of gallons of fuel that has ever been stored in this tank? (That is, how full have you actually filled it?) [ENTER QUANTITY IN GALLONS]

LARGEST QUANTITY HELD IN TANK: ________ gallons /34-39

T5. In what year was this tank installed?

YEAR OF INSTALLATION: ____________ /40-43

T6. Was this tank new or used when it was installed? [CIRCLE ONLY ONE CODE]

NEW [SKIP TO T8]. 1
USED [GO ON TO T7]. 2
DON'T KNOW [SKIP TO T8] . . . 8
/44

T7. How old was this tank when it was installed?

AGE IN YEARS: ____________ /45-47

T8. Is this tank scheduled for replacement or repair within the next 12 months? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2
/48

T9. Has this tank ever been repaired? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T10]. 1
NO [SKIP TO T12]. 2
DON'T KNOW [SKIP TO T12]. . . 8
/49

T10. In what year was this tank last repaired?

YEAR LAST REPAIRED: ____________ /50-53

T11. What types of repairs were done to this tank?

REPAIRS: ____________ /54-55

____

____________ /56-57

T12. Which of the following fuel types were stored in this tank during the past 12 months? [CIRCLE ONE CODE FOR EACH FUEL TYPE]

		YES	NO
a.	Leaded gasoline	1	2
b.	Unleaded gasoline	1	2
c.	Diesel fuel	1	2
d.	Aviation fuel	1	2
e.	Gasohol	1	2
f.	Other [SPECIFY]: ________	1	2

____________ /58-65

T13. Does this tank have a pump?

YES [GO ON TO T14]. 1
NO [SKIP TO T18]. 2
/66

T14. How many pumps are connected to this tank?

NUMBER OF PUMPS ____________ /67-69

T15. Does this tank have a "suction" or a "submerged" (pressure) pump delivery system? [CIRCLE ONLY ONE CODE]

SUCTION 01
SUBMERGED 02
OTHER [SPECIFY]: ________ 03

____________ /70-71

T16. How many dispensers (nozzles) are connected to this tank?

NUMBER OF NOZZLES: ____________ /72-74

T17. Do the product dispensers (nozzles) for this tank have meters to measure the total quantity of product that has been pumped from the tank? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2
/75

T18. Is this tank attached to another tank by pipes or lines? [CIRCLE ONLY ONE CODE]

YES [PLEASE SPECIFY THE TANK NUMBER(S) OF THE CONNECTED TANK(S)] ____ /76

____________ 1
NO. 2
/77-78

T19. How is this tank situated in relation to the water table? Is it: [CIRCLE ONLY ONE CODE]

Completely above the water table. . . . 01
Partially above and partially below the water table. 02
Or, is the top surface of the tank completely below the water table . . . 03
Other [SPECIFY]: ____________ 04
/79-80

T20. Does this tank have a manway or other means of being entered for internal inspection? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T21]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8
/81

T21. Has the interior of the tank ever been inspected? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T22]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8
/82

T22. When was the most recent internal inspection of this tank?

MOST RECENT INSPECTION: ____________ /83-86

T23. Has the tank ever been tested for leaks after it was placed in service? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T24]. 1
NO [SKIP TO T26]. 2
DON'T KNOW [SKIP TO T26]. . . 8
/87

T24. What test method was used to test the tank? (Please give the brand name of the test, if known, and describe the test procedure. If more than one method was used, describe all methods used.)

METHOD(S): ____________

____________ /88-89

____

____________ /90-91

03

TANK DESCRIPTION SHEET (Continued)

TANK NUMBER: ______

T25. In what year was the tank last tested by this/these methods?

YEAR LAST TESTED: ______ /16-19

T26. Of what material is this tank constructed? [CIRCLE ONLY ONE CODE]

FIBERGLASS-REINFORCED PLASTIC . 01
STEEL 02
OTHER [SPECIFY]: ______ 03

______ /20-21

T27. Is the inside of this tank lined? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T28]. 1
NO [SKIP TO T30]. 2
DON'T KNOW [SKIP TO T30]. . . 8

T28. In what year was the lining installed? /22

YEAR LINED: ______ /23-26

T29. Of what material is the liner constructed? [CIRCLE ONLY ONE CODE]

EPOXY-BASED RESINS. 01
FIBERGLASS REINFORCED PLASTIC . . . 02
ISOPHTHALIC POLYESTER-BASED RESINS. 03
POLYURETHANE-BASED RESINS 04
OTHER [SPECIFY]: ______ 05

______ /27-28

T30. Is the outside of this tank coated? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T31]. 1
NO [SKIP TO T32]. 2
DON'T KNOW [SKIP TO T32]. . . 8

T31. Of what material is the coating constructed? [CIRCLE ONLY ONE CODE] /29

FIBERGLASS EPOXY. 01
ASPHALTIC MATERIAL. 02
URETHANE. 03
COAL TAR EPOXY. 04
OTHER [SPECIFY]: ______ 05

______ /30-31

T32. Is there secondary containment for this tank? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T33] 1
NO [SKIP TO T34] 2
DON'T KNOW [SKIP TO T34] 8

T33. Is this secondary containment a: /32

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall tank?. 04
or something else [SPECIFY]: ______ 05

______ /33-34

T34. Is there secondary containment for any equipment that is attached to this tank (such as pipes, pumps, valves, etc.)? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T35] 1
NO [SKIP TO T36] 2
DON'T KNOW [SKIP TO T36] 8

T35. Is this secondary containment a: /35

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall piping?. 04
or something else [SPECIFY]: ______ 05

______

T36. What is the name of the company that installed the tank?

INSTALLER: ______ /38-39

T37. Is there a paved surface over the tank?

YES [GO ON TO T38] 1
NO [SKIP TO T40] . . . . 2 /40

T38. Is this pavement:

asphalt?. 01
concrete? 02
gravel? 03
other [SPECIFY]: ______ 04

______ /41-42

T39. How thick is the pavement?

THICKNESS: ______ /43-45

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ______ /46-47

______ 03

T40. What is the distance from the surface to the top of the tank?

DISTANCE TO SURFACE: ______ /48-50

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ______ /51-52

______ 03

T41. Does this tank have any of the following kinds of protection against corrosion? [CIRCLE ONLY ONE CODE FOR EACH ITEM]

		Yes	No	
a.	Passive cathodic protection (using sacrificial anodes)? . .	1	2	/53
b.	Cathodic protection using impressed current?.	1	2	/54
c.	Other [SPECIFY]: ______	1	2	/55

______

T42. Has this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE] 56-57

YES [GO ON TO T43] 1
NO [SKIP TO T44] 2
DON'T KNOW [SKIP TO T44] . . . 8

T43. How was the leak detected and/or verified? [CIRCLE ALL THAT APPLY] /58

INVENTORY RECONCILIATION . . . 01 /59-60
ENVIRONMENTAL MONITORING . . . 02 /61-62
FACILITY INSPECTION. . . . . . 03 /63-64
TANK TESTING . . . . 04 /65-66
OTHER [SPECIFY]: ______

______ 05 /67-68

T44. Have the lines (piping) for this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /69
DON'T KNOW 8

02

TANK DESCRIPTION SHEET

TANK
NUMBER: ____________

T1. What is the capacity of this tank? (That is, what is the maximum number of gallons of fuel it can hold?) [ENTER CAPACITY IN GALLONS]

TANK DESIGN CAPACITY: ____________ gallons
16-21

T2. What is the average amount of fuel in this tank just before a delivery? (That is, what is the low point of the product level?) [ENTER QUANTITY IN GALLONS]

AVERAGE CONTENTS BEFORE DELIVERY: ________ gallons
22-27

T3. What is the average amount of fuel delivered to this tank? [ENTER QUANTITY IN GALLONS]

AVERAGE SIZE OF DELIVERY: ____________ gallons
/28-33

T4. What is the maximum number of gallons of fuel that has ever been stored in this tank? (That is, how full have you actually filled it?) [ENTER QUANTITY IN GALLONS]

LARGEST QUANTITY HELD IN TANK: __________ gallons
/34-39

T5. In what year was this tank installed?

YEAR OF INSTALLATION: ____________
/40-43

T6. Was this tank new or used when it was installed? [CIRCLE ONLY ONE CODE]

NEW [SKIP TO T8]. 1
USED [GO ON TO T7]. 2
DON'T KNOW [SKIP TO T8] . . . 8
/44

T7. How old was this tank when it was installed?

AGE IN YEARS: ____________
/45-47

T8. Is this tank scheduled for replacement or repair within the next 12 months? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2
/48

T9. Has this tank ever been repaired? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T10]. 1
NO [SKIP TO T12]. 2
DON'T KNOW [SKIP TO T12]. . . 8
49

T10. In what year was this tank last repaired?

YEAR LAST REPAIRED: ____________
/50-53

T11. What types of repairs were done to this tank?

REPAIRS: ____________
/54-55
____
____
56-57

T12. Which of the following fuel types were stored in this tank during the past 12 months? [CIRCLE ONE CODE FOR EACH FUEL TYPE]

		YES	NO
a.	Leaded gasoline	1	2
b.	Unleaded gasoline	1	2
c.	Diesel fuel	1	2
d.	Aviation fuel	1	2
e.	Gasohol	1	2
f.	Other [SPECIFY]: __________	1	2

____
/58-65

T13. Does this tank have a pump?

YES [GO ON TO T14]. 1
NO [SKIP TO T18]. 2
/66

T14. How many pumps are connected to this tank?

NUMBER OF PUMPS ____________
/67-69

T15. Does this tank have a "suction" or a "submerged" (pressure) pump delivery system? [CIRCLE ONLY ONE CODE]

SUCTION 01
SUBMERGED 02
OTHER [SPECIFY]: __________ 03
____
/70-71

T16. How many dispensers (nozzles) are connected to this tank?

NUMBER OF NOZZLES: ____________
/72-74

T17. Do the product dispensers (nozzles) for this tank have meters to measure the total quantity of product that has been pumped from the tank? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2
/75

T18. Is this tank attached to another tank by pipes or lines? [CIRCLE ONLY ONE CODE]

YES [PLEASE SPECIFY THE
TANK NUMBER(S) OF
THE CONNECTED TANK(S)] ____ /76
____________ 1
NO. 2
/77-78

T19. How is this tank situated in relation to the water table? Is it: [CIRCLE ONLY ONE CODE]

Completely above the water table. . . . 01
Partially above and partially below the water table. 02
Or, is the top surface of the tank completely below the water table . . . 03
Other [SPECIFY]: ____________ 04
/79-80

T20. Does this tank have a manway or other means of being entered for internal inspection? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T21]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8
/81

T21. Has the interior of the tank ever been inspected? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T22]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8
/82

T22. When was the most recent internal inspection of this tank?

MOST RECENT INSPECTION: ____________
83-86

T23. Has the tank ever been tested for leaks after it was placed in service? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T24]. 1
NO [SKIP TO T26]. 2
DON'T KNOW [SKIP TO T26]. . . 8
/87

T24. What test method was used to test the tank? (Please give the brand name of the test, if known, and describe the test procedure. If more than one method was used, describe all methods used.)

METHOD(S): ____________
____
88-89
____
____
90-91

031

TANK DESCRIPTION SHEET (Continued)

TANK NUMBER: ______________

T25. In what year was the tank last tested by this/these methods?

YEAR LAST TESTED: ______________________ /16-19

T26. Of what material is this tank constructed? [CIRCLE ONLY ONE CODE]

FIBERGLASS-REINFORCED PLASTIC . 01
STEEL 02
OTHER [SPECIFY]: ______________ 03
______________________ /20-21

T27. Is the inside of this tank lined? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T28]. 1
NO [SKIP TO T30]. 2
DON'T KNOW [SKIP TO T30]. . . 8 /22

T28. In what year was the lining installed?

YEAR LINED: ______________ /23-26

T29. Of what material is the liner constructed? [CIRCLE ONLY ONE CODE]

EPOXY-BASED RESINS. 01
FIBERGLASS REINFORCED PLASTIC . . . 02
ISOPHTHALIC POLYESTER-BASED RESINS. 03
POLYURETHANE-BASED RESINS 04
OTHER [SPECIFY]: ______________ 05
______________________ /27-28

T30. Is the outside of this tank coated? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T31]. 1
NO [SKIP TO T32]. 2
DON'T KNOW [SKIP TO T32]. . . 8 /29

T31. Of what material is the coating constructed? [CIRCLE ONLY ONE CODE]

FIBERGLASS/EPOXY. 01
ASPHALTIC MATERIAL. 02
URETHANE. 03
COAL TAR EPOXY. 04
OTHER [SPECIFY]: ____________ 05
______________________ /30-31

T32. Is there secondary containment for this tank? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T33] 1
NO [SKIP TO T34] 2
DON'T KNOW [SKIP TO T34] . . . . . . 8 /32

T33. Is this secondary containment a:

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall tank?. 04
or something else [SPECIFY]: ______ 05
______________________ 33-34

T34. Is there secondary containment for any equipment that is attached to this tank (such as pipes, pumps, valves, etc.)? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T35] 1
NO [SKIP TO T36] 2
DON'T KNOW [SKIP TO T36] 8 35

T35. Is this secondary containment a:

concrete basin?. 01
plastic-lined earth basin? 02
clay-lined basin?. 03
double-wall piping?. 04
or something else [SPECIFY]: ______ 05
______________________ 36-37

T36. What is the name of the company that installed the tank?

INSTALLER: ______________________ /38-39

T37. Is there a paved surface over the tank?

YES [GO ON TO T38] 1
NO [SKIP TO T40] . . . . 2 /40

T38. Is this pavement:

asphalt?. 01
concrete? 02
gravel? 03
other [SPECIFY]: ____________ 04
______________________ /41-42

T39. How thick is the pavement?

THICKNESS: ______________ /43-45

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ________ /46-47
______________________ 03

T40. What is the distance from the surface to the top of the tank?

DISTANCE TO SURFACE: __________ /48-50

[CIRCLE ONE]:
INCHES 01
FEET 02
OTHER [SPECIFY]: ________ /51-52
______________________ 03

T41. Does this tank have any of the following kinds of protection against corrosion? [CIRCLE ONLY ONE CODE FOR EACH ITEM]

		Yes	No	
a.	Passive cathodic protection (using sacrificial anodes)? . .	1	2	/53
b.	Cathodic protection using impressed current?.	1	2	/54
c.	Other [SPECIFY]: ____________	1	2	/55

______________________ /56-57

T42. Has this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T43] 1
NO [SKIP TO T44] 2
DON'T KNOW [SKIP TO T44] . . . 8 /58

T43. How was the leak detected and/or verified? [CIRCLE ALL THAT APPLY]

INVENTORY RECONCILIATION . . . 01 59-60
ENVIRONMENTAL MONITORING . . . 02 61-62
FACILITY INSPECTION. 03 63-64
TANK TESTING 04 65-66
OTHER [SPECIFY]: ____________
______________________ 05 67-68

T44. Have the lines (piping) for this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE]

YES. 1
NO 2 69
DON'T KNOW 8

02

TANK DESCRIPTION SHEET

TANK NUMBER: ____________

T1. What is the capacity of this tank? (That is, what is the maximum number of gallons of fuel it can hold?) [ENTER CAPACITY IN GALLONS]

TANK DESIGN CAPACITY: ____________ gallons /16-21

T2. What is the average amount of fuel in this tank just before a delivery? (That is, what is the low point of the product level?) [ENTER QUANTITY IN GALLONS]

AVERAGE CONTENTS BEFORE DELIVERY: ________ gallons 22-27

T3. What is the average amount of fuel delivered to this tank? [ENTER QUANTITY IN GALLONS]

AVERAGE SIZE OF DELIVERY: ____________ gallons 28-33

T4. What is the maximum number of gallons of fuel that has ever been stored in this tank? (That is, how full have you actually filled it?) [ENTER QUANTITY IN GALLONS]

LARGEST QUANTITY HELD IN TANK: __________ gallons /34-39

T5. In what year was this tank installed?

YEAR OF INSTALLATION: ____________ /40-43

T6. Was this tank new or used when it was installed? [CIRCLE ONLY ONE CODE]

NEW [SKIP TO T8]. 1
USED [GO ON TO T7]. 2
DON'T KNOW [SKIP TO T8] . . . 8

/44

T7. How old was this tank when it was installed?

AGE IN YEARS: ____________ /45-47

T8. Is this tank scheduled for replacement or repair within the next 12 months? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2

/48

T9. Has this tank ever been repaired? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T10]. 1
NO [SKIP TO T12]. 2
DON'T KNOW [SKIP TO T12]. . . 8

/49

T10. In what year was this tank last repaired?

YEAR LAST REPAIRED: ____________ /50-53

T11. What types of repairs were done to this tank?

REPAIRS: ____________ /54-55

____

____________ /56-57

T12. Which of the following fuel types were stored in this tank during the past 12 months? [CIRCLE ONE CODE FOR EACH FUEL TYPE]

		YES	NO
a.	Leaded gasoline	1	2
b.	Unleaded gasoline	1	2
c.	Diesel fuel	1	2
d.	Aviation fuel	1	2
e.	Gasohol	1	2
f.	Other [SPECIFY]: ________	1	2

____

58-65

T13. Does this tank have a pump?

YES [GO ON TO T14]. 1
NO [SKIP TO T18]. 2

/66

T14. How many pumps are connected to this tank?

NUMBER OF PUMPS ____________ /67-69

T15. Does this tank have a "suction" or a "submerged" (pressure) pump delivery system? [CIRCLE ONLY ONE CODE]

SUCTION 01
SUBMERGED 02
OTHER [SPECIFY]: __________ 03

____

/70-71

T16. How many dispensers (nozzles) are connected to this tank?

NUMBER OF NOZZLES: ____________ 72-74

T17. Do the product dispensers (nozzles) for this tank have meters to measure the total quantity of product that has been pumped from the tank? [CIRCLE ONLY ONE CODE]

YES 1
NO. 2

/75

T18. Is this tank attached to another tank by pipes or lines? [CIRCLE ONLY ONE CODE]

YES [PLEASE SPECIFY THE
TANK NUMBER(S) OF
THE CONNECTED TANK(S)] ____ /76
____________ 1
NO. 2

/77-78

T19. How is this tank situated in relation to the water table? Is it: [CIRCLE ONLY ONE CODE]

Completely above the water table. . . . 01
Partially above and partially
below the water table. 02
Or, is the top surface of the tank
completely below the water table . . . 03
Other [SPECIFY]: ____________ 04

/79-80

T20. Does this tank have a manway or other means of being entered for internal inspection? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T21]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8

/81

T21. Has the interior of the tank ever been inspected? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T22]. 1
NO [SKIP TO T23]. 2
DON'T KNOW [SKIP TO T23]. . . 8

/82

T22. When was the most recent internal inspection of this tank?

MOST RECENT INSPECTION: ____________ 83-86

T23. Has the tank ever been tested for leaks after it was placed in service? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T24]. 1
NO [SKIP TO T26]. 2
DON'T KNOW [SKIP TO T26]. . . 8

/87

T24. What test method was used to test the tank? Please give the brand name of the test, if known, and describe the test procedure. If more than one method was used, describe all methods used.

METHOD(S): ____________

____________ 88-89

____

____________ 90-91

TANK DESCRIPTION SHEET (Continued)

TANK NUMBER: ______________

T25. In what year was the tank last tested by this/these methods?

YEAR LAST TESTED: ______________

/16-19

T26. Of what material is this tank constructed? [CIRCLE ONLY ONE CODE]

FIBERGLASS-REINFORCED PLASTIC .	01
STEEL	02
OTHER [SPECIFY]: ______________	03

____

/20-21

T27. Is the inside of this tank lined? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T28].	1
NO [SKIP TO T30].	2
DON'T KNOW [SKIP TO T30]. . .	8

T28. In what year was the lining installed? /22

YEAR LINED: ______________

/23-26

T29. Of what material is the liner constructed? [CIRCLE ONLY ONE CODE]

EPOXY-BASED RESINS.	01
FIBERGLASS REINFORCED PLASTIC . . .	02
ISOPHTHALIC POLYESTER-BASED RESINS.	03
POLYURETHANE-BASED RESINS	04
OTHER [SPECIFY]: ______________	05

____

/27-28

T30. Is the outside of this tank coated? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T31].	1
NO [SKIP TO T32].	2
DON'T KNOW [SKIP TO T32]. . .	8

/29

T31. Of what material is the coating constructed? [CIRCLE ONLY ONE CODE]

FIBERGLASS EPOXY.	01
ASPHALTIC MATERIAL.	02
URETHANE.	03
COAL TAR EPOXY.	04
OTHER [SPECIFY]: __________	05

____

/30-31

T32. Is there secondary containment for this tank? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T33]	1
NO [SKIP TO T34]	2
DON'T KNOW [SKIP TO T34]	8

T33. Is this secondary containment a: /32

concrete basin?.	01
plastic-lined earth basin?	02
clay-lined basin?.	03
double-wall tank?.	04
or something else [SPECIFY]: ______	05

____

/33-34

T34. Is there secondary containment for any equipment that is attached to this tank (such as pipes, pumps, valves, etc.)? [CIRCLE ONLY ONE CODE]

YES [GO ON TO T35]	1
NO [SKIP TO T36]	2
DON'T KNOW [SKIP TO T36]	8

T35. Is this secondary containment a: /35

concrete basin?.	01
plastic-lined earth basin?	02
clay-lined basin?.	03
double-wall piping?.	04
or something else [SPECIFY]: ______	05

____

/36-37

T36. What is the name of the company that installed the tank?

INSTALLER: ______________

T37. Is there a paved surface over the tank? /38-39

YES [GO ON TO T38]	1
NO [SKIP TO T40]	2

T38. Is this pavement: /40

asphalt?.	01
concrete?	02
gravel?	03
other [SPECIFY]: __________	04

____

T39. How thick is the pavement? /41-42

THICKNESS: ______________ /43-45

[CIRCLE ONE]:

INCHES	01
FEET	02
OTHER [SPECIFY]: ________ /46-47	
______________	03

T40. What is the distance from the surface to the top of the tank?

DISTANCE TO SURFACE: __________ /48-50

[CIRCLE ONE]:

INCHES	01
FEET	02
OTHER [SPECIFY]: ________ 51-52	
______________	03

T41. Does this tank have any of the following kinds of protection against corrosion? [CIRCLE ONLY ONE CODE FOR EACH ITEM]

	Yes	No	
a. Passive cathodic protection (using sacrificial anodes)? . .	1	2	/53
b. Cathodic protection using impressed current?.	1	2	/54
c. Other [SPECIFY]: __________	1	2	55

____

T42. Has this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE] /56-57

YES [GO ON TO T43]	1
NO [SKIP TO T44]	2
DON'T KNOW [SKIP TO T44] . . .	8

T43. How was the leak detected and/or verified? [CIRCLE ALL THAT APPLY] /58

INVENTORY RECONCILIATION . . .	01	59-60
ENVIRONMENTAL MONITORING . . .	02	61-62
FACILITY INSPECTION.	03	63-64
TANK TESTING	04	65-66
OTHER [SPECIFY]: __________		
______________	05	67-68

T44. Have the lines (piping) for this tank ever been found to be leaking? [CIRCLE ONLY ONE CODE]

YES.	1	
NO	2	69
DON'T KNOW	8	

B. OPERATING PRACTICES

04

B1. Do you (or another establishment employee) inventory the contents of your tank(s) by measuring the depth of the contents with a dipstick? [CIRCLE ONLY ONE CODE]

YES [GO ON TO B2]. . . . . 1 /16

NO [SKIP TO B5] 2

B2. How often do you inventory the tank contents? [CIRCLE ONLY ONE CODE]

TWICE DAILY. 01
DAILY. 02
WEEKLY 03
EVERY TWO WEEKS. . . . . 04 /17-18
MONTHLY. 05

OTHER [SPECIFY]:________________________ 06

B3. Do you have a chart (or charts) that show how to convert the depth of the product in the tank(s) to gallons? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /19

B4. Are the inventory (stick) readings recorded in a log or journal or other permanent record such as a daily inventory report? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /20

B5. Do any of the underground motor fuel storage tanks at this establishment have remote gauges (either float or electronic) that show the quantity of product in the tank? [CIRCLE ONLY ONE CODE]

YES [GO ON TO B6]. . . . . 1 /21
NO [SKIP TO B8]. 2

B6. How often do you (or another establishment employee) inventory the contents of your tank(s) by reading the remote gauge(s)? [CIRCLE ONLY ONE CODE]

TWICE DAILY. 01
DAILY. 02
WEEKLY 03
EVERY TWO WEEKS. . . . . 04 /22-23
MONTHLY. 05

OTHER [SPECIFY]: ________________________ 06

B7. Are the inventory (gauge) readings recorded in a log or journal or other permanent record such as a daily inventory report? [CIRCLE ONLY ONE CODE]

YES	1	/24
NO	2	

B8. Do the product dispensers for your tank(s) have meters that record the total quantity of fuel that has been pumped from the tank(s)? [CIRCLE ONLY ONE CODE]

YES [GO ON TO B9]	1	/25
NO [SKIP TO B16]	2	

B9. Do you (or another establishment employee) check and record the dispenser meter readings for the tank(s)?

YES [GO ON TO B10]	1	/26
NO [SKIP TO B12]	2	

B10. How often do you check and record the dispenser meter readings? [CIRCLE ONLY ONE CODE]

TWICE DAILY	01	/27-28
DAILY	02	
WEEKLY	03	
EVERY TWO WEEKS	04	
MONTHLY	05	
OTHER [SPECIFY]:____________________	06	

B11. Are the dispenser meter readings recorded in a log or journal or other permanent record such as a daily inventory report? [CIRCLE ONLY ONE CODE]

YES	1	/29
NO	2	

B12. Do you (or another establishment employee) check the accuracy of your dispenser meters to make sure the meters correctly measure the amount pumped? [CIRCLE ONLY ONE CODE]

YES	1	/30
NO	2	

B13. Does anyone other than you or another establishment employee (such as a state or county Weights and Measures official) check the accuracy of your dispenser meters? [CIRCLE ONLY ONE CODE]

YES	1	/31
NO	2	

314. How often is the accuracy of your dispenser meters checked? [CIRCLE ONLY ONE CODE]

IF THE ACCURACY OF YOUR DISPENSER METERS IS NEVER CHECKED, CHECK HERE ☐ AND SKIP TO B16. /32

DAILY	01	
WEEKLY	02	
EVERY TWO WEEKS	03	
MONTHLY	04	/33-34
ANNUALLY	05	
OTHER [SPECIFY]: ____________________	06	

B15. About how often is it necessary to recalibrate (adjust the gauge of) your dispenser meters? [CIRCLE ONLY ONE CODE]

DAILY	01	
WEEKLY	02	
EVERY TWO WEEKS	03	
MONTHLY	04	/35-36
ANNUALLY	05	
OTHER [SPECIFY]: ____________________	06	

B16. Approximately how often do you receive deliveries to your tank(s)?

FREQUENCY: ____________________ /37-39

[CIRCLE ONE]:

PER WEEK	01	
PER MONTH	02	/40-41
OTHER [SPECIFY]: ____________________ ____________________	03	

B17. Are inventory (stick or remote gauge) readings of your tank(s) taken immediately before receiving a fuel delivery? [CIRCLE ONLY ONE CODE]

YES	1	/42
NO	2	

B18. Are inventory (stick or remote gauge) readings of your tank(s) taken immediately after receiving a fuel delivery? [CIRCLE ONLY ONE CODE]

YES.	1	/43
NO	2	

B19. Is the quantity delivered to each tank recorded in a log or journal or other permanent record such as a daily inventory report? [CIRCLE ONLY ONE CODE]

YES.	1	/44
NO	2	

B20. Do you reconcile your inventory (stick or remote gauge) readings with your book inventory (meter readings and deliveries)?

YES [GO ON TO B21]	1	/45
NO [SKIP TO B22]	2	

B21. How often do you reconcile your tank inventory (stick or remote gauge) readings with your book inventory (meter readings and deliveries)? [CIRCLE ONLY ONE CODE]

DAILY.	01	
WEEKLY	02	
EVERY TWO WEEKS.	03	
MONTHLY.	04	/46-47
ANNUALLY	05	
OTHER [SPECIFY] ______________________	06	

B22. Do you ever use water-finding paste to check the water level in the bottom of your tank(s)? [CIRCLE ONLY ONE CODE]

YES [GO ON TO B23]	1	/48
NO [SKIP TO C1].	2	

B23. How often do you use water-finding paste to check the water level in the bottom of your tank(s)? [ENTER FREQUENCY AND CIRCLE UNIT CODE]

FREQUENCY: ______________________ /49-51

[CIRCLE ONE]:

PER DAY	01	
PER WEEK.	02	
PER MONTH	03	/52-53
PER YEAR.	04	
OTHER [SPECIFY]: ________________	05	

____

C. OPERATING HISTORY

05

C1. Have any tanks at this establishment ever been replaced? [CIRCLE ONLY ONE CODE]

YES [GO ON TO C2]. . . . . 1 /16
NO [SKIP TO C4]. 2
DON'T KNOW [SKIP TO C4]. 8

C2. How many tanks have been replaced?

NUMBER REPLACED: ______________________ /17-19

C3. Please answer the following questions about each tank that has been replaced, beginning with the tank that was replaced most recently. [SPACE HAS BEEN PROVIDED FOR UP TO FOUR TANKS. IF MORE THAN FOUR TANKS HAVE BEEN REPLACED, WRITE THE ANSWERS FOR THE ADDITIONAL TANKS ON A PLAIN SHEET OF PAPER.]

	First Tank	Second Tank	Third Tank	Fourth Tank
C3a. In what year was the (first/second/third) tank replaced?	________ (year) /20-23	________ (year) /36-39	________ (year) /52-55	________ (year) /68-71
C3b. Why was the tank replaced? [CIRCLE ALL THAT APPLY FOR EACH TANK]				
a. Because it was leaking?. . . .	01	01	01	01
b. Because other tanks were being replaced at that time? . . .	02	02	02	02
c. Because it was no longer needed/in use?.	03	03	03	03
d. To increase storage capacity.	04	04	04	04
e. Or for some other reason? [SPECIFY]: .	05 ________ (specify) /24-35	05 ________ (specify) /40-51	05 ________ (specify) /56-67	05 ________ (specify) /72-83

06

C4. Have any tanks at this establishment ever been removed without being replaced? [CIRCLE ONLY ONE CODE]

YES [GO ON TO C5]. 1
NO [SKIP TO C7]. . . . . 2 /16
DON'T KNOW [SKIP TO C7]. 8

C5. How many tanks have been removed without being replaced?

NUMBER REMOVED: ______________________________ /17-19

C6. Please answer the following questions about each tank that has been removed without being replaced. [SPACE HAS BEEN PROVIDED FOR UP TO FOUR TANKS. IF MORE THAN FOUR TANKS HAVE BEEN REMOVED WITHOUT BEING REPLACED, WRITE THE ANSWERS FOR THE ADDITIONAL TANKS ON A PLAIN SHEET OF PAPER]

	First Tank	Second Tank	Third Tank	Fourth Tank
C6a. In what year was the (first/second/third) tank removed?	________ (year) /20-23	________ (year) /34-37	________ (year) /48-51	________ (year) /62-65
C6b. Why was the tank removed? [CIRCLE ALL THAT APPLY FOR EACH TANK]				
a. Because it was leaking?. . . .	01	01	01	01
b. Because other tanks were being removed at that time? . . .	02	02	02	02
c. Because it was no longer needed/in use?.	03	03	03	03
d. Or for some other reason [SPECIFY]: .	04 ________ (specify) /24-33	04 ________ (specify) /38-47	04 ________ (specify) /52-61	04 ________ (specify) /66-74

07

C7. Have any tanks at this establishment been abandoned in place? ("Abandoned in place" means that the tank is no longer in use but has not been removed.) [CIRCLE ONLY ONE CODE]

YES [GO ON TO C8]. 1
NO [SKIP TO D1]. . . . . 2 /16
DON'T KNOW [SKIP TO D1]. 8

C8. How many tanks have been abandoned?

NUMBER ABANDONED: ____________________ /17-19

C9. Please answer the following questions about each tank that has been abandoned in place. [SPACE HAS BEEN PROVIDED FOR UP TO FOUR TANKS. IF MORE THAN FOUR TANKS HAVE BEEN ABANDONED IN PLACE, WRITE THE ANSWERS FOR THE ADDITIONAL TANKS ON A PLAIN SHEET OF PAPER]

	First Tank	Second Tank	Third Tank	Fourth Tank
C9a. In what year was the (first/second/third) tank abandoned?	______ (year) /20-23	______ (year) /44-47	______ (year) /68-71	______ (year) /92-95
C9b. Why was the tank abandoned? [CIRCLE ALL THAT APPLY FOR EACH TANK]				
a. Because it was leaking	01	01	01	01
b. Because it was no longer needed/in use	02	02	02	02
c. Or for some other reason [SPECIFY]: .	03	03	03	03
	______ (specify) /24-31	______ (specify) /48-55	______ (specify) /72-79	______ (specify) /96-103
C9c. How was the tank abandoned? [DESCRIBE PROCEDURE, OR CIRCLE ALL THAT APPLY]				
a. Tank was drained. .	01	01	01	01
b. Tank was washed . .	02	02	02	02
c. Tank was cut open .	03	03	03	03
d. Tank was sand filled.	04	04	04	04
e. Tank was cement filled.	05	05	05	05
f. Other [SPECIFY]: ______ ______	______ (specify) /32-43	______ (specify) /56-67	______ (specify) /80-91	______ (specify) /104-115

D. PERMITS AND LICENSES

08

D1. Were you required to obtain a special building permit or license in order to have your tank(s) installed? [CIRCLE ONLY ONE CODE]

YES.	1	
NO	2	/16
DON'T KNOW	8	

D2. Are you required to maintain a special permit or license to store flammable or hazardous material at your establishment? (Often these permits are called Hazardous Use or Hazardous Materials permits, and are issued by the state, county, or local fire marshal.) [CIRCLE ONLY ONE CODE]

YES.	1	
NO	2	/17
DON'T KNOW	8	

E. INSTALLATION

E1. What type of fill was used to backfill around and over the tank(s)? [CIRCLE ONLY ONE CODE]

a. Clean sand (with no large rock)?	01	
b. Pearock or pea gravel?	02	
c. Soil from the excavation?	03	/18-19
d. Or some other kind of fill [SPECIFY]: .	04	

____

____

E2. (Is the tank/are any of the tanks) installed with the bottom resting on or in a concrete or packed earth pad? [CIRCLE ONE CODE FOR EACH ITEM]

	Yes	No	
a. A concrete pad or cradle?	1	2	/20
b. A packed earth pad?	1	2	/21

E3. Are any of the tanks strapped to a concrete pad? [CIRCLE ONLY ONE CODE]

YES.	1	
NO	2	/22
DON'T KNOW	8	

E4. What is the shortest distance between any of your tanks and any neighboring underground tank or other solid underground structure (such as a basement wall, sewer, or utility vault)? [ENTER DISTANCE AND CIRCLE UNIT CODE]

SHORTEST DISTANCE FROM UNDERGROUND STRUCTURE: ________________ /23-28

[CIRCLE ONE]:

INCHES.	01	
FEET.	02	/29-30
OTHER [SPECIFY]: ________________	03	

____

F. PROTECTION

09

F1. Has any type of special equipment or materials been installed to prevent external corrosion of the tank(s)? [CIRCLE ONLY ONE CODE]

YES [SPECIFY AND GO ON TO F2]: ____________ /16
____________________________________ 1
NO [SKIP TO F3] . . . . 2 /17-18
DON'T KNOW [SKIP TO F3]. 8

F2. How often do you inspect your external corrosion protection system? [ENTER FREQUENCY AND CIRCLE UNIT CODE]

> IF YOU NEVER INSPECT THE EXTERNAL CORROSION PROTECTION SYSTEM, CHECK HERE ☐ AND SKIP TO F3.

/19

FREQUENCY OF INSPECTION: ______________ /20-22

[CIRCLE ONE]:
PER DAY 01
PER WEEK. 02
PER MONTH . . . . 03 /23-24
PER YEAR. 04
OTHER [SPECIFY]: ____________________ 05
____

F3. Since you began using the tank(s), have you ever had the tank(s) completely drained and cleaned out? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /25

F4. Does the tank system have a continuous electronic monitoring system to detect tank leakage? [CIRCLE ONLY ONE CODE]

YES [GO ON TO F5]. 1
NO [SKIP TO F6] . . . . 2 /26

F5. How often is the electronic monitoring system inspected for maintenance? [CIRCLE ONLY ONE CODE]

a. Annually? 01
b. Twice a year? 02
c. Three or four times a year? . . . . . . 03 /27-28
d. Or at some other interval? [SPECIFY]:

________________________________ 04

____

F6. Have pressure piping (or line) leak detectors been installed at this establishment to detect leaks in the piping (lines)? [CIRCLE ONLY ONE CODE]

YES [GO ON TO F7]. 1
NO [SKIP TO G1]. . . . . 2 /29
DON'T KNOW [SKIP TO G1]. 8

F7. How frequently are the pressure piping leak detectors tested to make sure they are operating correctly?

> IF THE PRESSURE PIPING LEAK DETECTORS ARE NEVER TESTED, CHECK HERE ☐
> AND SKIP TO QUESTION G1.

/30

FREQUENCY: ________________________ /31-33

[CIRCLE ONE]:

PER DAY. 01
PER WEEK 02
PER MONTH. . . . . 03 /34-35
PER YEAR 04
OTHER [SPECIFY]: ____________________ 05

F8. Have the pressure piping leak detectors ever given false leak signals? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /36
DON'T KNOW 8

F9. Have the pressure piping leak detectors ever detected actual leaks in the piping system? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /37
DON'T KNOW 8

G. INFORMATION NEEDS

10

G1. Have any of the companies from whom you receive your fuel products asked you to keep inventory records (dipstick readings, meter readings and delivery records) for your tank(s)? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /16

G2. Has anyone ever given you training or explanatory literature about any of the following topics? [CIRCLE ONE CODE FOR EACH ITEM. IF YOU HAVE RECEIVED INFORMATION OR TRAINING, PLEASE INDICATE FROM WHOM]

Type of Training	Did you receive?		If "Yes," from whom?	
	YES	NO		
a. Keeping inventory records..................	1	2		/17-19
b. Doing inventory reconciliation calculations...............................	1	2		/20-22
c. Measuring the quantity of product in a tank using a dipstick and conversion chart..........................	1	2		/23-25
d. Checking pump meter accuracy...............	1	2		/26-28
e. Line leak detection and testing............	1	2		/29-31
f. Tank or line leak prevention...............	1	2		/32-34
g. Tank tightness testing methods.............	1	2		/35-37
h. Leak monitoring methods (such as observation wells).........................	1	2		/38-40

G3. If you found out that (your tank/one of your tanks) was leaking, would you probably: [CIRCLE ONLY ONE CODE]

a. Replace it with another tank 01
b. Line it and continue to use it . . . . 02 /41-42
c. Abandon it in place. 03
d. Or something else [SPECIFY]: ______________________________ 04
____

G4. How much do you expect it would cost you to:

a. Replace a tank? . . . . $______ /43-48
b. Line a tank?. . . . . $______ /49-54
c. Abandon a tank in place? . . . . $______ /55-60

G5. Do you have an insurance policy that covers you against damage to people or property caused by sudden spills of motor fuel? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /61

G6. Do you have an insurance policy that covers you against damage to people or property resulting from non-sudden spills (including leaks) of motor fuel? [CIRCLE ONLY ONE CODE]

YES. 1
NO . . . . 2 /62

TANK TO DISPENSER METER FUEL LINE CONNECTIONS

Instructions: Mark (X) in each block for which there is fuel line (pipe) connection from the tank to the dispenser meter. (If more tanks than spaces, use additional sheets.)

Disp. Meter Number	Tank Number and Product							
	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8
M-1								
M-2								
M-3								
M-4								
M-5								
M-6								
M-7								
M-8								
M-9								
M-1-								
M-11								
M-12								
M-13								
M-14								
M-15								
M-16								
M-17								
M-18								
M-19								
M-20								

Does the facility have a leak monitoring system (for tanks or piping) that is not electronic (such as observation wells)?

YES 1
NO 2

If YES, describe ____________________________________

____

Site Observations Recording Sheet

Site Code Label ____________________

Date __________

	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6
Size of fill pipe (I.D.)						
Drop Tube (permanent or removable)						

- -

Site Code Label ____________________

Date __________

	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6
Size of fill pipe (I.D.)						
Drop Tube (permanent or removable)						

OMB No.: 2070-0037
Expires: December 31, 1985

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

UNDERGROUND STORAGE TANK SURVEY

LABEL VERIFICATION

MAILING ADDRESS: Verified? ... ☐

____
(ESTABLISHMENT NAME)

____
(ADDRESS)

____
(CITY/STATE/ZIP)

LOCATION ADDRESS: Verified? ... ☐

____
(ESTABLISHMENT NAME)

____
(ADDRESS)

____
(CITY/STATE/ZIP)

CONTACT NAME AND PHONE: Verified? ... ☐

Contact Name: ______________________ Contact Phone: ______________________

A. Questionnaire Status: ______________________

B. Inventory Status (CIRCLE ONE)

1 = Started
2 = Not Started
3 = Obtained
4 = Refused
5 = Other (SPECIFY) ______________________

C. Can Test (CIRCLE ONE)

1 = No Meters
2 = Complete
3 = Partial Complete
4 = Refused
5 = Other (SPECIFY) ______________________

D. Mapping (CIRCLE ONE)

1 = Complete
2 = Other (SPECIFY) ______________________

E. Debriefing (CIRCLE ONE)

1 = Complete
2 = Other (SPECIFY) ______________________

F. Confidentiality

1 = Form Enclosed
2 = Waived
3 = Other (SPECIFY) ______________________

Conducted by:

WESTAT
An Employee-Owned Research Corporation
1650 Research Blvd. • Rockville MD 20850 • 301 251-1500

[IN YOUR TELEPHONE CALL TO SET UP THE APPOINTMENT, ASK R IF HE/SHE HAS COMPLETED THE QUESTIONNAIRE FORM AND BEGUN THE INVENTORY RECORDING. IF NOT, ENCOURAGE THE R TO DO SO.]

INTRODUCTION:

1. Hello, my name is (YOUR NAME), from Westat. [SHOW IDENTIFICATION CARD]. I'm here to conduct the interview with you about your underground storage tank(s). The other member of my team is ______________________ from Midwest Research Institute. (He/She) will be drawing a map of the tank area(s) and taking some pictures of the surface area(s) over the tank(s).

   [IF YOU HAVE ANY OBSERVERS ON THIS INTERVIEW, INTRODUCE YOUR OBSERVERS. OTHERWISE, ASK IF THERE IS A PLACE WHERE YOU AND THE RESPONDENT CAN SIT DOWN AND GO THROUGH THE QUESTIONNAIRE. A SIDE-BY-SIDE SEATING ARRANGEMENT IS PREFERABLE, SINCE THIS ALLOWS YOU TO READ FROM THE RESPONDENT'S WORKING COPY OF THE QUESTIONNAIRE. IF THE R DOES NOT HAVE HIS SURVEY MATERIALS IN SIGHT, SUGGEST THAT HE OBTAIN THEM -- THAT THE INTERVIEW WILL BE MORE EFFICIENT, AND THAT YOU WILL HAVE TO RECORD CERTAIN INFORMATION ON HIS INVENTORY FORMS LATER ON.]

CONFIDENTIALITY:

2. As was mentioned in the letter and in the General Instructions, you can (claim/ask for) confidentiality for all or part of your responses to the questionnaire. The way you do this is by filling out the form that is in the General Instructions booklet. Have you decided to claim confidentiality for any of your answers?

   YES........ 1 [OBTAIN COMPLETED CONFIDENTIALITY FORM FROM RESPONDENT. PUT ID STICKER ON TOP OF FORM.]
   NO......... 2

[BEGIN INTERVIEW, READING QUESTIONS, ITEM-BY-ITEM. READ THROUGH THE TANK DESCRIPTION SHEET ONLY FOR THE FIRST TANK. FOR THE SECOND AND FOLLOWING TANKS, READ THE QUESTION NUMBERS AND/OR ABBREVIATED QUESTIONS.]

INVENTORY RECORDS:

3. Next, we need to review your inventory records. The General Instructions booklet discussed keeping inventory records for each of your tanks. Have you started to keep these records yet?

   YES........ 1 (GO TO 4)
   NO......... 2 (GO TO 5)

4. (IF YES): That's great! Here is a postage paid envelope in which to send the completed inventories to Westat. A Westat interviewer will be calling you in a few weeks to check with you on any problems you might be having with the inventories. While I am here, I need to review your inventory sheets and initial them. [IF NECESSARY, PROBE: If I could take a look at them now, I would appreciate it.] [IF THE TANK(S) DISPENSER(S) ARE METERED]: I will also need to record the results of my metering can tests of the dispenser meters on the inventory sheets for each tank. (GO TO 8)

5. (IF NO): Is there any reason why you have not started the inventories?

   YES........ 1 SPECIFY: ______________________________
   ______________________________ (GO TO 6)
   NO......... 2 (GO TO 6)

6. Will you be able to start the inventories today?

   YES........ 1 (GO TO 7)
   NO......... 2 [PROBE FOR WHEN THEY WILL BEGIN:
   ______________________] (GO TO 7)
   REFUSED.... 7 (TERMINATE)
   IMPOSSIBLE. 9 [SPECIFY WHY: ______________
   ______________________] (TERMINATE)

7. Here is a postage paid envelope in which to send the completed inventories to Westat.

8. When we receive your inventory(ies) they will be computerized and run through a computer program that checks for gains and losses that can't be accounted for, such as over- and under-deliveries, theft or pilfering, or leakage. We will let you know the results of that computer analysis.

DISPENSER METER ACCURACY CHECKS:

We have found in the past that a major problem in analyzing inventory records is that some dispenser meter readings are just slightly inaccurate. Often these meter errors show up in the computer analysis as small leaks. For that reason, we are checking out the accuracy of all dispenser meters, using a 5-gallon meter testing can.

Our accuracy checking procedure is the same procedure that is used by the agencies that certify meter accuracy. We will not be adjusting your meters if we find that they are misreading. What we will do is record the amount of product pumped intgo the can according to the dispenser meter, and record the amount in the metering can according to the gauge on the can. I'll need to record this on your inventory sheets as well as my copy of the questionnaire. The information will be fed into the computer program to correct for metering error in the results.

We will be pumping five gallons of product into the test can from each dispenser that has its own meter. We will then be pouring the five gallons of product back into the tank from which it was pumped. IF R HAS BEGUN INVENTORY: I will need to record the returned product as a "delivery" to the tank on your inventory sheet. FOR THE FIRST MEASUREMENT: First, I need to wet the inside of the can with about a gallon of product, and pour it back into its tank.

MAKE SURE YOU WILL BE ABLE TO RETURN THE PRODUCT TO THE TANK BEFORE YOU BEGIN PUMPING. DO ALL THE METERS FOR A TANK BEFORE MOVING ON TO THE NEXT PRODUCT TYPE. AFTER ALL OF THE TANKS ARE DONE, WASH THE CAN OUT WITH DETERGENT AND WATER, AND DRY IT AS COMPLETELY AS POSSIBLE.

DEBRIEFING:

To be completed immediately after leaving the site.

D1. Did R have the questionnaire completed?

YES........ 1
NO........ 2

D2. Did R have the inventory sheets started?

YES........ 1 (GO TO D3)
NO......... 2 (GO TO D4)

D3. Did R have errors or problems in the completed parts of the inventory?

YES........ 1 (DESCRIBE: ____)
NO......... 2

D4. Did R understand inventory process?

YES........ 1
NO......... 2

D5. Did R understand most/all of the questions in the questionnaire?

YES........ 1
NO......... 2

D6. Was R:

	YES	NO
a. cooperative?............................	1	2
b. hostile?................................	1	2
c. guessing a lot?.........................	1	2
d. Other (SPECIFY) ____________________		
________________________________	1	2

D7. Was it necessary to talk to more than one R to obtain all required information?

YES........ 1
NO......... 2

D8. Comments: ____

____

TIME BEGAN: ________ A.M.
P.M.
TIME ENDED: ________ A.M.
P.M.

RECORD OF CALLS

ATTEMPT NUMBER	DAY	TIME	RESULT CODE	COMMENTS/PROBLEMS
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		
		am pm		

RESULT CODES

PRELIMINARY RESULT CODES

1 APPOINTMENT
2 RESPONDENT NOT AVAILABLE
3 RESPONDENT NOT LOCATED
4 RESPONDENT ILL
5 REFUSAL/BREAKOFF
6 RESPONDENT BROKE APPOINTMENT
7 LANGUAGE PROBLEM
8 OTHER
9 OUT-OF-SCOPE

FINAL - MAIL TO SUPERVISOR

11 COMPLETE
12 PARTIAL COMPLETE
13 ESTABLISHMENT CANNOT BE LOCATED
14 RESPONDENT UNAVAILABLE
15 REFUSAL/BREAKOFF
16 RESPONDENT AVOIDING INTERVIEW
17 LANGUAGE PROBLEM: NO INTERPRETER
18 NO TANKS
19 OUT OF PSU (MOVED)
20 OUT OF BUSINESS (CLOSED)
99 OTHER (SPECIFY) ______________
____

INSTRUCTIONS

PREPARATIONS FOR TANK TESTING

1. If you are not responsible for making the following testing arrangements, please notify those who are as soon as possible. Please notify other persons who may be involved, including the tank owner and those at your firm's or regional offices.

2. Immediately contact your fuel supplier or distributor to make arrangements for filling your tanks. Explain any tank filling problems to the test coordinator from Midwest Research Institute (MRI) when he calls.

3. Fill any business vehicles before the fuel drop off. As necessary, make arrangements for alternate sources of fuel for those vehicles on the test day.

4. Fuel delivery must be finished before 8:00 a.m. of the test day. If the test crew has to wait for fuel drop off, it means that testing will not be finished until later that evening.

5. **Completely fill each tank** until the fuel level comes up into neck of the fill pipe. Use your tank dipsticks to determine when the tanks are "full": the fuel depth, as measured by the dipstick, should equal the tank diameter. (In many tanks, you can see when the fuel reaches the fill pipe neck. However, for tanks with drop tubes, you must use the dipstick to know when it is full.) Testing cannot be done if the tanks are not completely full.

6. Once filled, the tanks cannot be used until testing is complete. Make arrangements to keep the tanks out of service. Your business does not need to be closed during this time, but the tanks must remain inactive.

FINAL CHECKLIST

☐ Notify responsible individuals.
  ☐ Owner
  ☐ Main or regional office
  ☐ Others

☐ Contact supplier or distributor

☐ Fill business vehicles before filling tanks

☐ Fill tanks before 8:00 a.m. on test day

☐ **Fill tanks completely**

☐ Arrange to keep tanks out of service

ENVIRONMENTAL CONDITIONS DATA SHEET

Site Code Label ____________________

Date ____________________ Tank No. ____________

Test Firm ____________________

Test Team ____________________

Time	Temperature °F				
	Barometric Pressure	Surface	Ambient	Subsurface	Comments

Climatic conditions.

TEMPERATURE PROFILE DATA

Site Code Label ____________________

Test Team ____________________ Date __________

Test Crew ____________________ Tank No. __________

START TIME							
	D	U	D	U	D	U	D
END TIME							

Figure 3

Site Diagram and Detail Diagram Sheet

Site Code Label

Map # ________________ Test Firm ________________

Test Team ________________ Date ________________

Sketch Area and Dimensions

PICTURE DESCRIPTION

Site Code Label

Team ______________________ Date ______________

Picture No.	Description
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	

Critical Features Data Sheet

Site Code Label

Team ______________________

Date ______________

Tank No.	Type of Product	Number of Dispensors According to Product	Size of Tank	Size of Fill Pipe	Size of Gauge Pipe	Size of Stick Pipe	Size of Vent. Pipe	Drop Tube Permanent, Removable	Delivery System Pressure, Suction	Pump Pit If Present	Depth of Tank From Grade	Surface Over Tank	Electrical Power Outlets	Powerlines Overhead	Waterways

Site Code Label

Team ______________________________ Date ________________

EDIT CHECKLIST

☐ Site code label on all pages.

☐ Be sure all maps are numbered sequentially.

☐ Photographs of critical parameters.

☐ Site code labels on photographs and filed in notebook.

☐ Check to see that all data sheets are filled our correctly.

SIMULATED LEAK TEST
VOLUME DATA

Site Code Label

Date ____________________

Tank No. ________________

Test Team ________________________________

Test Firm ________________________________

Volume, g				
Time	Bottle No.	Final Wt.	Tare Wt.	Total Wt.

Specific Gravity:
Temperature:

SIMULATED LEAK DATA FORM
LEAKING UNDERGROUND STORAGE TANK

Site Code Label

Test Crew ____________________ Date ____________ Tank No. ______

Test Team ______________________________

Rotameter No.	Rotameter Setting mm	Nominal Rate gph	Start Time Clock	End Time Hour	Elapsed Time gms	Measured Volume gph	Calculated Rate

Petro Tite
TANK TESTER

HEATH CONSULTANTS
100 TOSCA DRIVE
P.O. BOX CS-200
STOUGHTON, MA. 02072-0086
(617) 344-1400

14. ______________________________
Name of Supplier, Owner or Dealer — Address No. and Street(s) — City — State — Date of Test

15. TANK TO TEST

______________ Identify by position

______________ Brand and Grade

16. CAPACITY

Nominal Capacity__________ Gallons

Is there doubt as to True Capacity? ☐
See Section "DETERMINING TANK CAPACITY"

By most accurate capacity chart available__________ Gallons

From
- ☐ Station Chart
- ☐ Tank Manufacturer's Chart
- ☐ Company Engineering Data
- ☐ Charts supplied with petro tite
- ☐ Other __________

17. FILL-UP FOR TEST

Stick Water Bottom before Fill-up __________ to ⅛ in. = __________ Gallons

Fill up. STICK BEFORE AND AFTER EACH COMPARTMENT DROP OR EACH METERED DELIVERY QUANTITY

Tank Diameter

	Stick Readings to ⅛ in.	Gallons	Total Gallons ea. Reading
Inventory			
Product in full tank (up to fill pipe)			

18. SPECIAL CONDITIONS AND PROCEDURES TO TEST THIS TANK

See manual sections applicable. Check below and record procedure in log (26).

☐ Water in tank ☐ High water table in tank excavation ☐ Line(s) being tested with LVLLT

VAPOR RECOVERY SYSTEM
- ☐ Stage I
- ☐ Stage II

19. TANK MEASUREMENTS FOR TSTT ASSEMBLY

Bottom of tank to Grade* .... ________"
Add 30" for 4" L .... ________"
Add 24" for 3" L or air seal .... ________"
Total tubing to assemble Approximate .... ________"

20. EXTENSION HOSE SETTING

Tank top to grade* .... ________"
Extend hose on suction tube 6" or more below tank top .... ________"

*If Fill pipe extends above grade, use top of fill.

21. TEMPERATURE/VOLUME FACTOR (e) TO TEST THIS TANK

Is Today Warmer? ( ) Colder? ( ) ____° F Product in Tank ____° F Fill-up Product on Truck ____° F Expected Change (+ or −)

22. Thermal-Sensor reading after circulation __________ digits __________ Nearest °F

23. Digits per °F in range of expected change__________ digits

24. __________ total quantity in full tank (16 or 17) × __________ coefficient of expansion for involved product = __________ volume change in this tank per °F gallons

25. __________ volume change per °F (24) ÷ __________ Digits per °F in test Range (23) = __________ Volume change per digit. Compute to 4 decimal places. This is test factor (e)

26. LOG OF TEST PROCEDURES			30. HYDROSTATIC PRESSURE CONTROL		31. VOLUME MEASUREMENTS (V) RECORD TO .001 GAL.			34. TEMPERATURE COMPENSATION USE FACTOR (e)			38. NET VOLUME CHANGES EACH READING	39. ACCUMULATED CHANGE
27. DATE TIME (24 hr.)	28. Record details of setting up and running test. (Use full length of line if needed.)	29. Reading No.	Standpipe Level in Inches		32. Product in Graduate		Product Replaced (−) Product Recovered (+)	35. Thermal Sensor Reading	36. Change Higher + Lower − (t)	37. Computation (t) × (e) = Expansion + Contraction −	Temperature Adjustment Volume Minus Expansion (+) or Contraction (−) #33(V) − #37(T)	At High Level record Total End Deflection At Low Level compute Change per Hour (NFPA criteria)
			Beginning of Reading	Level to which Restored	Before Reading	After Reading						

Data Chart for Tank System Tightness Test

petro Tite
TANK TESTER

PLEASE PRINT

1. OWNER Property ☐ Tank(s) ☐

Name Address Representative Telephone

Name Address Representative Telephone

2. OPERATOR

Name Address Telephone

3. REASON FOR TEST (Explain Fully)

4. WHO REQUESTED TEST AND WHEN

Name Title Company or Affiliation Date

Address Telephone

5. WHO IS PAYING FOR THIS TEST?

Company, Agency or Individual Person Authorizing Title Telephone

Billing Address City State Zip

Attention of: Order No. Other Instructions

6. TANK(S) INVOLVED

Identify by Direction	Capacity	Brand/Supplier	Grade	Approx. Age	Steel/Fiberglass

7. INSTALLATION DATA

Location	Cover	Fills	Vents	Siphones	Pumps
North inside driveway, Rear of station, etc.	Concrete, Black Top, Earth, etc.	Size, Titefill make, Drop tubes, Remote Fills	Size, Manifolded	Which tanks?	Suction, Remote, Make if known

8. UNDERGROUND WATER

Depth to the Water table ______________________"

Is the water over the tank? ☐ Yes ☐ No

9. FILL-UP ARRANGEMENTS

Tanks to be filled ______ hr. ____________ Date Arranged by ______________________
Name Telephone

Extra product to "top off" and run TSTT. How and who to provide? Consider NO Lead.

Terminal or other contact for notice or inquiry______________________
Company Name Telephone

10. CONTRACTOR, MECHANICS, any other contractor involved

11. OTHER INFORMATION OR REMARKS

Additional information on any items above. Officials or others to be advised when testing is in progress or completed. Visitors or observers present during test etc.

12. TEST RESULTS

Tests were made on the above tank systems in accordance with test procedures prescribed for petro Tite TANK TESTER as detailed on attached test charts with results as follows:

Tank Identification	Tight	Leakage Indicated	Date Tested

13. CERTIFICATION

This is to certify that these tank systems were tested on the date(s) shown. Those indicated as "Tight" meet the criteria established by the National Fire Protection Asociation Pamphlet 329.

Date

Serial No. of Thermal Sensor

Technicians

Testing Contractor or Company. By: Signature

Address

F-97

Double Check COMPANY INCORPORATED
4616 PROSPECT KANSAS CITY, MO. 64130
PHONE (816) 921-5832

LIQUID VOLUMETRIC LINE LEAK TEST

DATE OF TEST ____________
JOB # ____________

1 LOCATION: ____________ Street No. and/or Corner ____________ City ____________ State
2 OWNER: ____________ Name ____________ Address ____________ Representative ____________ Position ____________ Telephone No.
3 OPERATOR: ____________ Name ____________ Dealer, Mgr. or Other ____________ Address (if different than Location) ____________ Telephone No.
4 REASON FOR TEST ____________ Telephone No.
____
5 TEST REQUESTED BY: ____________ Name ____________ Position ____________ Order No. ____________ Billing Address
6 SPECIAL INSTRUCTIONS: ____________
7 CONTRACTOR OR COMPANY MAKING TEST MECHANIC(S) NAME ____________
8 IS A K-M TANK TEST TO BE MADE WITH THIS LINE TEST? ☐ YES ☐ NO
9 MAKE AND TYPE OF PUMP OR DISPENSERS ____________
10 WEATHER ____________ TEMPERATURE IN TANKS ______ °F ______ °C
COVER OVER LINES ____________ Concrete, Black Top, etc.
APPROXIMATE BURIAL DEPTH ____________

11 IDENTIFY EACH LINE AS TESTED	12 TIME (MILITARY)	13 LOG OF TEST PROCEDURES, AMBIENT TEMPERATURE, WEATHER, ETC.	14 PRESSURE		15 VOLUME			16 TEST RESULTS
			psi OR kPa		BURETTE READING		NET CHANGE	
			BEFORE	AFTER	BEFORE	AFTER		CONCLUSIONS, REPAIRS AND COMMENTS

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11 IDENTIFY EACH LINE AS TESTED	12 TIME (MILITARY)	13 LOG OF TEST PROCEDURES, AMBIENT TEMPERATURE, WEATHER, ETC.	14 PRESSURE		15 VOLUME			16 TEST RESULTS
			psi OR kPa		BURETTE READING		NET CHANGE	CONCLUSIONS, REPAIRS AND COMMENTS
			BEFORE	AFTER	BEFORE	AFTER		

SCALE: ☐ 1 PACE = 3 FT. PER SQUARE—THIS SHEET = 168' x 114'
☐ 2 PACES = 6 FT. PER SQUARE—THIS SHEET = 336' x 228'

17 SKETCH OF LOCATION

SHOW: NORTH N 1. STREETS, STATION BUILDING, TANKS, ISLANDS, PIPING (IF KNOWN, OR BEST INFO). PUMPS OR DISPENSERS (USE NUMBERS ONLY IF PERMANENTLY MARKED).

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APPENDIX G

NATIONAL UNDERGROUND STORAGE TANK SURVEY
NATIONAL SAMPLE OF FARMS

I. INTRODUCTION AND SUMMARY

The survey of underground motor fuel storage tanks is designed to provide national estimates of the number of underground motor fuel storage tanks at the end use point and the number and percent of these tanks which leak. The survey design defined three segments of the overall target universe of establishments with underground motor fuel storage tanks:

- Fuel establishments (gas stations and establishments in other fuel-related or fuel-using industries) which by the nature of their business are likely to have such tanks;
- Large establishments (20 or more employees) which by virtue of their size may have an underground motor fuel storage tank; and
- Farms, of which over half have motor fuel storage capacity, but an unknown proportion store motor fuel underground.

The sample design for the survey is a two-stage cluster design. The first stage is survey locations, called Primary Sampling Units (PSUs) and consisting of counties or groups of counties. The contiguous United States was divided into six survey regions, based on rough similarity of soil type and condition, as defined in Figure G-1. Thirty-four PSUs were drawn, six from each region, except four PSUs were drawn from Region 5.

Figure G-1. Six regions for National Survey of Underground Storage Tanks

1 -- Northeast

- Maine
- New Hampshire
- Vermont
- Connecticut
- Massachusetts
- Rhode Island
- New York
- New Jersey
- Pensylvania
- Maryland
- Delaware
- Virginia
- West Virginia
- Washington, D. C.

2 -- Southeast

- Kentucky
- Tennessee
- Arkansas
- Louisiana
- Mississippi
- Alabama
- Georgia
- North Carolina
- South Carolina
- Florida

3 -- Midwest

- Wisconsin
- Minnesota
- Iowa
- Missouri
- Illinois
- Indiana
- Ohio
- Michigan

4 -- Central

- North Dakota
- South Dakota
- Nebraska
- Kansas
- Oklahoma
- Texas

5 -- Mountain

- Montana
- Wyoming
- Idaho
- Nevada
- Utah
- Colorado
- Arizona
- New Mexico

6 -- Pacific

- Washington
- Oregon
- California

Among the three survey segments, fuel establishments and large establishments are both concentrated in the same areas, where the population is. Drawing a sample of PSUs which is optimal for both of these segments is therefore no problem, because they occur together. Farms, however, tend to be found in the opposite places, those with sparse population. So optimizing the design for farms is in direct opposition to optimizing the design for fuel establishments and large establishments. Since the fuel establishments are the major focus of the survey, accounting for about 800 of the approximately 920 expected establishments with underground motor fuel storage tanks, the sample of PSUs was optimized for fuel establishments by being drawn in proportion to the number of fuel establishments in each PSU. As noted above, the resulting sample of PSUs is not optimal for studying farms.

The second stage of sampling is the sample of establishments within the selected PSUs. Three sample frames (master lists) were developed for the 34 sampled PSUs -- one for fuel establishments, one for large establishments, and one for farms. Samples were drawn from each list:

- 1618 fuel establishments;
- 600 large establishments; and
- 600 farms.

These establishments were contacted to determine whether they were eligible for our survey; that is, whether they had underground motor fuel storage tanks. The eligibility rates were (approximately):

- 50 percent for fuel establishments;
- 15 percent for large establishment; and
- Less than 5 percent for farms.

This appendix discusses the national farm sample of 600 farms to be screened. Subsection II discusses the target universe of farms and describes the farm sampling frame on a national basis. The 1982 Census of Agriculture conducted by the Census Bureau is taken as the standard count of farms, and a list developed by the Agricultural Stabilization and Conservation Service (ASCS) of the U.S. Department of Agriculture (USDA) is the sample frame used. For the nation, overall, this frame offers good coverage of the farm universe. Subsection III reviews the survey design with reference to the farm sample and compares Census figures with ASCS figures for the selected PSUs. In this subsection, it is seen that the coverage of farms by the frame is weak in some parts of the country. Section IV concludes the appendix with a discussion of the ratio-adjustment weighting method proposed to minimize total sampling error in the farm estimates.

II. TARGET UNIVERSE OF FARMS AND SAMPLING FRAME

A. Two Farm Data Sources

Two sources of information on farms were used in designing and conducting this survey. One is the 1982 Census of Agriculture (the most recent) conducted by the Bureau of the

Census. This source is used as the most reliable source of national statistics about farms. The second is the "1983 Deficiency Master File" developed by the Agricultural Stabilization and Conservation Service (ASCS) of the U.S. Department of Agriculture (USDA), which is used as the list, or sampling frame, for farms.

The Census of Agriculture is a data collection and tabulation effort which is as inclusive as possible. The 1982 Census lists 2,240,976 farms in the U.S. A farm is defined by Census as "any place from which $1000 or more of agricultural products were sold or normally would have been sold during the Census year." Tables provide breakdowns of these farms by size of farm, value of sales, type of crop, etc., both nationally, by state and by county. Some of these figures are reviewed later in this section.

What the Census of Agriculture does not provide is a list of farms or farm operators in specific places. Thus, for an actual sampling frame we used the USDA/ASCS 1983 Deficiency File. This is a list of farms developed by the USDA containing about 1,942,000 listings (87 percent as many as the Census total). The original impetus for the development of the file was to provide a mechanism for payment distribution for the PIK (Payment-in-Kind) program for 1983. In 1983, the PIK program was so popular that USDA believes that almost everyone engaged in growing PIK program crops (which include various cash grains and upland cotton) applied for it, and hence is listed on the Deficiency File. Because they saw a chance to have a near-Census of farms on a data file, USDA made a special effort to also include listings of farms not eligible for the PIK program. The basic data were gathered by the ASCS county agents.

The official USDA/ASCS statistics indicate that of 2,018,000 farms known to the ASCS, 1,942,000 (or 96 percent) are listed on the Deficiency File. The ASCS definition of a farm is all of the land farmed under one operation.

Only about 57 percent of the farms listed on the Deficiency File (1,116,000 farms) are farms that are eligible for the PIK program. The remaining 43 percent of farms on the list are not eligible for the PIK program. Some portion of the ineligible farms are ineligible because they were not growing PIK program crops, others because they did not choose to apply for the PIK program. Because of the 96 percent coverage of farms known to them, ASCS believes the Deficiency File is a very complete list of farms in the U.S.

In exploring the universe of farms and comparing the two data sources, we take the 1982 Census of Agriculture as the primary source of information on the nation's farms. Although the ASCS total is less than the Census total, it is probable that the ASCS list is not simply a subset of the farms counted by the Census, but a partially overlapping list. This is due to the fact that the two lists are constructed by different organizations for different purposes, are based on different information, and have different definitions as for including and counting specific cases. However, we can get a summary of the nation's farms from the Census and a rough idea of the ASCS coverage of those farms.

B. Summary of the Target Universe Based on the 1982 Census of Agriculture

The figures presented here are taken from Vol. 1, Part 51, U.S. Summary and State Totals of the 1982 Census of Agriculture.

The first table lists total numbers of farms by size and sales categories.

It seems likely that farms with small acreage or low sales volume would be less likely to have underground motor fuel storage tanks and would also be less likely to be included on the ASCS file than large farms. Table G-1 indicates that a number of farms are quite small, with 8 percent of farms reported having one to nine total acres. Also, many farms have quite low sales figures. Nearly one-quarter of farms reported on had less than $2,500 in sales in 1982.

The Census also gives figures for storage of various fuels (although unfortunately for our survey, no question was asked as to whether the storage was underground). Table G-2 summarizes the storage capacity data for 1982.

This indicates that roughly half of all farms reported gasoline or gasohol storage, and about 40 percent reported diesel storage. The overlap of the two groups is not given but is presumably fairly high. However, the number of farms with substantial storage capacity is much less -- 2 percent reported 2,000 gallons or more diesel storage capacity, and 1 percent reported that much gas storage capacity. Taking 1,000 gallons or more as a cutoff, 7 percent of farms reported this much gasoline storage capacity and 8 percent reported this much diesel storage capacity.

In conclusion, based on the 1982 Census of Agriculture, there were about 2.2 million farms, of which 8 percent were smaller than 10 acres, one-quarter had less than $2,500 in sales for the year, and perhaps 10 percent have 1,000 gallons or more fuel storage capacity. This last assumes a substantial overlap between storers of gasoline and diesel fuel. If there is little

Table G-1. **Farms by acreage and sales**
(1982 Census of Agriculture)

Total U.S. Farms			2,240,976
By acreage			
1 - 9			187,665
10 or more			2,053,311
10 - 49		449,252	
50 - 499		1,238,162	
500 - 1,999		301,320	
2,000 or more		64,577	
By sales			
Less than $2,500			536,327
$2,500 or more			1,702,973
$2,500 - $9,999		560,010	
$10,000 or more		1,142,963	
$10,000 - $99,999	840,583		
$100,000 - $499,999	274,580		
$500,000 or more	27,800		

(1,676 abnormal farms not reported by sales - institutional, research and experimental farms, and Indian reservations.)

Table G-2. Fuel storage capacity, 1982*
(1982 Census of Agriculture)

Farms reporting fuel expenses	Gasoline and Gasohol	Diesel fuel
Storage capacity reported, farms	1,123,463	924,863
1,000's gallons	583,853	648,605
Farms with storage capacity of:		
1 - 499 gallons	616,650	471,646
500 - 999 gallons	352,925	262,902
1,000 - 1,999 gallons	136,455	140,896
2,000 or more gallons	17,433	49,419
Storage capacity reported as "no", farms	451,895	150,210
Storage capacity not reported, farms	422,083	245,380

*Includes above-ground tanks and containers, as well as underground tanks.

overlap, as many as 15 percent of farms may have 1,000 gallons or more motor fuel storage capacity.

C. Comparison of Census and Sample Frame

The sampling frame, the ASCS 1983 Deficiency File, is primarily a data base of farms rather than a source of statistics. Hence, we do not have extensive national or state statistics on this file. Nationally, we can compare the number of farms from Census (2,240,976) and the ASCS file (1,942,437), showing that the sample frame file has 87 percent as many farms as the Census. (Note that these are not necessarily completely a subset of the Census farms, as mentioned above.)

We also can compare total cropland acreage between the two data sources. The Census shows 445,362,028 acres of total cropland on 2,010,609 farms with cropland, while ASCS shows 443,850,049 acres of total cropland on its 1,942,437 farms. The ASCS definition of cropland is "tillable soil" -- the land does not have to have been planted, only to be suitable for planting. The Census definition includes three categories:

- Harvested cropland;
- Cropland use only for pasture or grazing; and
- Other cropland.

The two definitions appear to be quite similar.

The sample frame thus covers 99.7 percent of the total cropland reported in the Census and has 96.6 percent as many farms as those reporting cropland in the Census. It appears that farms with no cropland is an area of sparse coverage for the ASCS list. The major categories of land in farms not included in total cropland are:

- Pasture and rangeland other than cropland and woodland pastured (418,264,264 acres);
- Woodland (87,088,255 acres); and
- Land in house lots, ponds, roads, etc. (36,082,032 acres).

So farms with pasture, rangeland or woodland and no cropland are more likely to be in the Census but not the ASCS list. However, in the Census 90 percent of farms listed had cropland, so farms with none are relatively rare.

Other types of farms which may tend to under-represented by the ASCS list (based on discussions with Tom Meyer of ASCS) would be growers of fruits and vegetables. Most farms grow more than one crop, and so many fruit or vegetable farms may also have a PIK-eligible crop or may be listed as an ineligible farm on the ASCS file. According to Census data, 69,109 (3.1%) of farms reported vegetables harvested for sale and 123,663 (5.5%) reported land in orchards. On a national basis, these farms do not represent a major portion of the target universe, although on a regional basis their proportion varies. These figures are presented as a way of assessing the potential for undercoverage, but we have no direct way of determining the ASCS coverage of these types of farms.

III. SAMPLE DESIGN FOR UST SURVEY, FARM SEGMENT

In this subsection we again review the survey sample design, emphasizing the aspects relevant to the farm sample. The design was a two-stage cluster design. The contiguous U.S. was divided into six survey regions, as presented in Figure G-1 shown earlier. The first stage of the sample was survey locations, known as Primary Sampling Units (PSUs). These PSUs consisted of counties or groups of counties and were chosen by region with probability proportional to number of fuel establishments. The second stage was the within-PSU selection of farms. Farms were selected from a sampling frame based on the ASCS list for the selected counties with within-PSU probabilities determined so that the overall probabilities of selection would be equal for all farms. We give more details in the following sections.

A. First Stage Sample of Survey Sites (PSUs)

The first stage in the two-stage sample design was of PSUs, which were counties or groups of counties. Within each region, six PSUs (four in the Mountain Region) were selected with probability proportional to their number of gas stations and fuel-related establishments. As discussed in Subsection I, this is the optimal design for studying fuel establishments -- the main focus of the survey.

Table G-3 shows some statistics on number of farms, by region, based on the 1982 Census of Agriculture. The first two columns give the total farms in each region and the corresponding expected sample size, by region, for an equal probability sample of 600 farms to be screened for underground motor fuel storage tanks. Regions 1, 5 and 6 have expected sample sizes of less than 100, with Regions 5 and 6 less than 50. Next, in column 3, we have used the inverse of the PSU probability of selection as a PSU weight and weighted the 1982 Census of Agriculture farm counts for the selected PSUs up to the regional level. By comparing these figures with column 1, we see that our sample of PSUs has considerable variance from the actual totals. As

Table G-3. Farm summary based on 1982 Census of Agriculture, all farms

Region[1]	Agriculture Census count	Expected farm sample[2]	Weighted count, sampled PSU's	Expected farm sample[2]
1-Northeast	222,099	60	123,714	36
2-South	548,926	147	283,226	82
3-Midwest	725,699	195	908,358	264
4-Central	464,680	125	494,029	144
5-Mountain	121,777	33	147,071	43
6-Pacific	152,630	41	104,164	30
Continental U.S. Total	2,235,811	601	2,060,562	599

[1] Regions are defined in Figure G-1.

[2] These farms are to be screened for the presence of underground motor fuel storage tanks.

mentioned in Subsection II, this is due to the PSU sample selection being based on the number of fuel establishments, a measure inversely correlated with the number of farms.

Finally, column 4 gives the expected sample size based on the 1982 Agriculture Census counts for our PSUs. Regions 5 and 6 are still very low, and Regions 1 and 2 have a lower sample size than expected from the regional totals.

B. ASCS List for Selected PSUs

The actual sample was drawn from a sample frame based on the ASCS 1983 Deficiency File. This file was described in Subsection II above on a national basis. Here, we compare the ASCS file counts to the Census counts for our sampled PSUs and present some relevant Census figures on a regional basis. The actual sample frame used was a modification of the ASCS file, which we describe below, leading to the final sample sizes.

In Table G-4, the Census of Agriculture counts are compared with the ASCS file counts for the sampled PSUs on a region-by-region basis. The third column shows the percent coverage the ASCS file had. For the 76 counties in our 34 PSUs as a group, the ASCS file had 70 percent as many listings as there were farms counted in the Census of Agriculture. On a region-by-region basis there is quite a bit of variation in this coverage. The ASCS list has good to excellent coverage of Regions 2 through 4, which together contain 70 percent of all farms according to the Census; and fair to poor coverage of the rest of the country. For Region 3, the Midwestern region, ASCS actually has more listings -- 118 percent as many as the Census. For Region 2 (South) and 4 (Central), the ASCS had fairly good coverage -- 90 percent and 79 percent as many listings, respectively, as the

Table G-4. Raw farm count based on sampled PSUs (1982 Census of Agriculture and 1982 ASCS Defiency File)

Region[1]	Raw counts, sampled PSU's		Percent Coverage ASCS File
	1982 Agriculture Census	1983 ASCS Deficiency File	
1-Northeast	3,743	1,573	42%
2-South	6,619	5,969	90%
3-Midwest	13,367	15,787	118%
4-Central	11,025	8,706	79%
5-Mountain	4,472	2,305	52%
6-Pacific	10,851	504	5%
Continental U.S. Total	50,077	34,844	70%

[1] Regions are defined in Figure G-1

Census. For Regions 5 (Mountain) and 1 (Northeast), the coverage was only about half -- 52 and 42 percent as many listings, respectively, in ASCS as the Census count. Finally, for Region 6 (Pacific), the coverage was very low -- the ASCS list had only 5 percent as many listings as the Census for this region.

Several attempts to understand these discrepancies have met with limited success. The two data sources rely on different bases to get their lists of farms and farm operators, employ different (and to a great extent not thoroughly documented) definitions of "a farm" and have different basic philosophies of the importance of complete coverage. We were able to determine that our ASCS list is a list with one record per farm, as defined by the County Agent, so that the comparison in Table G-4 is the relevant one.

We expected that vegetable, fruit or livestock farms would be at greater risk of under-representation on the ASCS list, so Table G-5 presents the counts of these types of farms by region, with the percent of all farms in the region, based on the 1982 Census. A farm may, of course, have crops in more than one category. For example, a cattle ranch with pastureland would likely also grow feed grain and be eligible for the PIK program. Farms with land in vegetables or orchards might also have PIK-eligible crops, or be on the ASCS File as ineligible. The most striking statistic in Table G-5 is that, while nationally 5.4 percent of farms have land in orchards, in Region 6 (Pacific), 33.7 percent of farms have land in orchards. It seems quite probable that this is a contributing factor to the severe discrepancy between the ASCS frame and the Census in that region. Region 1 (Northeast) has a higher rage of farms with vegetables (7% versus 3.1%) than the national average but scarcely enough to account for listing less than half of all farms in that region.

Table G-5. Regional data from 1982 Census of Agriculture on farms with land in vegetables, orchards, and pastureland

Region*	Farms with land in vegetables		Farms with land in orchards		Farms with pastureland	
	Number	Percent	Number	Percent	Number	Percent
1-Northeast	15,458	7.0%	12,740	5.7%	151,287	68%
2-South	19,978	3.6%	28,063	5.1%	355,467	65%
3-Midwest	17,629	2.4%	11,784	1.6%	413,446	57%
4-Central	4,761	1.0%	12,524	2.7%	353,149	76%
5-Mountain	2,858	2.3%	5,271	4.3%	82,766	68%
6-Pacific	7,638	5.0%	51,456**	33.7%	71,679	47%
Continental U.S. Total	68,322	3.1%	121,838	5.4%	1,427,794	64%

*Regions are defined in Figure G-1.

** California has 39,801 farms with land in orchards, including 10,481 with grapes, 7,512 with citrus, 6,119 with avocados, 3,664 with plums and prunes, 2,904 with apples and 2,898 with peaches.

Washington has 6,946 such farms including 5,406 with apples, 2,235 with pears, 2,066 with cherries and 1,042 with grapes.

Oregon has 4,709 such farms including 2,053 with apples, 1,717 with cherries and 1,316 with pears.

The basic pattern in Table G-4 is good coverage to over-coverage in those parts of the country which contain the majority of all farms (Regions 2, 3, and 4 contain 1,739,305 farms, or 78 percent of the total, see Table G-3), and fair to poor coverage in the remainder of the country. This underlying distribution of farms, combined with the pattern of over- and under-coverage and the PSU selection probabilities, results in a fairly decent national estimate of number of farms based on weighted ASCS data, even though the regional estimates are poor. These weighted figures are shown in Table G-6, along with the expected sample size based on weighed ASCS file counts. Regions 1, 5, and 6 continue to lose sample cases due to list undercoverage of those regions.

D. Sampling Frame and Actual Farm Sample

In order to use the ASCS list as a sampling frame, two modifications were made. First, the list of farms was collapsed into a list of farmers by aggregating records with the same name and address. We would thus be able to increase the number of farms sampled without increasing the costs by sampling 600 operators and interviewing them regarding "any farm land you own or operate" in the specific counties they were sampled for. For those few who reported underground storage tanks, we then determined which distinct farms have such tanks and how many. The second frame modification was due to the use of a purchased list for the large establishment segment of the overall survey. Any large establishments with agricultural SICs were removed from the large establishment frame and matched against the ASCS list. If they did not already appear on it, they were added to the frame.

Table G-6. Weighted farm counts from ASCS 1983 File, expected and actual sample sizes

Region[1]	Weighted counts, sampled PSU's		Farm sample size expected from ASCS file[2]
	1982 Agriculture Census	1983 ASCS Deficiency File	
1-Northeast	123,714	52,376	15
2-South	283,226	301,055	86
3-Midwest	908,358	1,105,519	314
4-Central	494,029	512,376	146
5-Mountain	147,071	132,621	38
6-Pacific	104,164	5,652	2
Continental U.S. Total	2,060,562	2,109,599	601

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[1] Regions are defined in Figure G-1

[2] These farms are to be screened for the presence of underground motor fuel storage tanks.

From the final frame of farm operators thus established, a sample of 600 cases was drawn with within-PSU probabilities set so that the entire sample had equal probability. Table G-7 reviews the results of farm operators by region, column 1 shows the distribution of farm operators by region, column 2 gives the number of distinct farms this represents, and column 3 shows the farm estimate based on the unadjusted sample weights. Comparing these estimates back to the Census totals in Table G-3, we see that there is quite a bit of region to region variation, although the grand total is fairly close. This indicates that a ratio adjustment would improve the sampling error of estimation for this survey, which we describe in the next subsection.

IV. STATISTICAL ADJUSTMENT OF WEIGHTS TO MINIMIZE SAMPLING VARIANCE

In the previous subsection, it became apparent that the actual sample of farms based on the ASCS list does not accurately reflect the regional distribution of farms as measured by the 1982 Census of Agriculture. Further, in subsection II we found that the underground tank survey regions are very unequal in numbers of farms. In order that our final estimates of number and proportion of farms with underground tanks reflect regional variation and totals more closely, we propose a system of adjustments to the sample weights by region. Since some of the six survey regions have such small sample sizes, we also propose, for farm estimates only, consolidating the survey regions into three areas which have about the same number of farms and which will have over 100 sample cases each. The proposed consolidation is given in Table G-8, which shows the three consolidated regions, their Census totals, the unadjusted sample estimates, and the approximate adjustment factor to apply to the sample weights so that our final sample estimates (of numbers of farms)

Table G-7. Results of farm sample draw

Region[1]	Number of farmers (operators) sampled[2]	Number of farms operated	Weighted number of farms using sample weight
1-Northeast	11	17	53,395
2-South	88	94	295,242
3-Midwest	324	354	1,111,868
4-Central	142	159	499,398
5-Mountain	33	33	103,649
6-Pacific	2	2	6,282
Continental U.S. Total	600	659	2,069,834

[1] Regions are defined in Figure G-1.

[2] These farms are to be screened for the presence of underground motor fuel storage tanks.

Table G-8. Consolidated regions for farm estimates and ratio adjustment factors

Regions	Consolidated region	1982 Census of Agriculture	Weighted sample, selection weights	Ratio adjustment factor (rounded)
1&2 - Northeast and Southeast	East	771,025	348,637	2.21
3-Midwest	Midwest	725,699	1,111,868	0.65
4,5&6-Central, Mountain and Pacific	West of the Mississippi	739,087	609,329	1.21

will equal the Census totals. The actual adjustment was made after the field work had been completed, so that the final number of actual farms contacted was used. After this adjustment, the ratio of largest to smallest weight was about 3.4 to 1, not an excessive gap.

In assessing the quality of the final estimates for farms, for these three consolidated regions and nationally, we have computed sample variances based on the final weights. There is a qualitative aspect to the accuracy as well, in which we acknowledge that coverage of the far West Coast especially is fairly low, and the estimates for the Western consolidated region may contain some bias if these three states are strongly different in terms of underground motor fuel storage from the rest of the west. However, since the West Coast accounts for only 20 percent of farms in Survey Regions 4, 5 and 6, it would have to be extremely different for the survey estimates of this consolidated region to be significantly affected.

APPENDIX H

ENVIRONMENTAL DATA COVERAGE

I. INTRODUCTION

Environmental data coverage by existing data bases and literature was explored for geographic locations of the OTS Leaking Underground Storage Tank survey.[1,2,3] Data sources were located and subsequently reviewed for their usefulness. From the pertinent literature and data sources found, environmental data sets were derived for survey areas and organized within an automated data base. Parameter choices were directed toward use in leak analyses and fuel migration modeling studies. The data sets were compiled into a Basic Site Information File containing locators, descriptors, and cross-reference keys pointing to additional soil, climate, and groundwater information for the sites in the survey. Fuel component chemical and physical data were also compiled and tabulated.[4]

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[1] "Literature Searching for Leaking Underground Storage Tank Project," General Software Corporation, 1985.

[2] "Environmental Scenario Assemblage for Leaking Underground Storage Tanks," General Software Corporation, 1985.

[3] "Environmental Scenarios Supporting Movement of Complex Mixtures to Groundwater," General Software Corporation, 1986

[4] "Chemical-Physical Parameters and Processes Effecting Petroleum Fuel Migration", General Software Corporation, 1985.

II. DATA SOURCE AVAILABILITY AND COVERAGE

In the search for soil, climate, and groundwater information, only major readily accessible sources were considered. These sources include, among others, the County Soil Surveys of the Soil Conservation Service, USGS publications, and the NAWDEX data base. A summary of the sources located and descriptions of the information which they contain are presented in Table H-1.

The County Soil Surveys of the Soil Conservation Service provide the most complete and comprehensive information on soil classification. The survey status of the original 76 counties in the LUST survey is provided in Table H-2. The SCS Soils-5 computerized data base contains most of the information covered in the published surveys. There were 914 site locations recorded, and of these, over 450 were covered by modern soil surveys, but approximately 150 of the latter were designated as urban land or mixed land complexes and were not fully described.

USGS publications and the NAWDEX Groundwater Site Inventory provide variable coverage for groundwater and subsurface geologic information. For areas not covered, regional ranges were recorded from "Ground-water regions of the United States" by R.C. Heath or from the ENVIRLOC database as cited in Table H-1. These ranges must be used with caution, however, since they are broad geographic approximations only.

To obtain up to date, reliable climatic information, parameters were requested directly from the National Oceanic and Atmospheric Administration (NOAA). Currently, NOAA is compiling parameter summaries from approximately 3000 U.S. Weather stations from their databases for the Exposure Evaluation Division of OTS. Publications summarizing portions of this data include the Climatic Atlas of the United States and the Statistical Abstract of the United States. Soil Surveys frequently contain brief climate summaries as well.

III. BASIC SITE INFORMATION FILE

The Basic Site Information File was designed in support of the Leaking Underground Storage Tank survey from the work performed in a preliminary study described in the Task 8 report of EPA Contract 68-02-3970. Data, data ranges, and cross reference keys covering a variety of locator, climate, soil, and groundwater information were included in the file to enable the user to have a general understanding of site location and conditions, and to obtain further information as necessary.

The file itself contains four sections: site location and identification, climate, soil, and groundwater/geologic. The parameters in the file and their corresponding lengths are shown in Table H-3. Tables H-4 through H-6 are examples from the Basic Site Information File.

A. Site Location and Identification

The site location and identification portion includes identifiers ranging in resolution from general region to specific site. These locators aid in the determination of the number of sites within a particular state, county, or region, and in the location of the actual site on a USGS topographic map.

The LUST Regions (Pacific, Mountain, Central, Midwest, Northeast, and Southeast) are the largest divisions contained in the file, dividing the United States into six parts for survey purposes. The PSU, or primary sampling unit, is a further division of the LUST Region which encompasses one or more counties. There are 34 PSUs included in the LUST Survey which cover a total of 76 counties.

The state and county FIPS codes, or Federal Information Processing Standards, are numeric codes for each state and county. The state and county codes are two and three digits respectively, and are sometimes combined into a single five digit identifier. Being a standard identifier, the FIPS Code helps to avoid confusion due to spelling errors and nonuniform abbreviations.

The USGS Topo Quad information is provided for easy reliable geographic location. This information includes the name of the topographic quadrangle on which the site may be found, the map scale of the quadrangle, and the bottom right coordinates of the map. This information may be useful in the future for digitization of mapping and site location.

Survey sites were usually received marked on a USGS topo map. Sometimes, however, sites were marked on nonstandard or state road maps, or occasionally not marked at all. If a topo quad could be determined for a site, this information was included in the file, otherwise it was omitted.

The Soil Survey Area information provides the name of the Soil Conservation Service County Soil Survey covering the site, the year the survey was published, and the survey area code. County soil surveys cover a county, group of counties, or sections of counties. Sites located in areas with no current published soil survey are labelled "Area not surveyed" at this point. Sites not marked, or marked on large scale maps are labelled "Site not specifically marked", or with some other pertinant descriptor. The Survey Area Code is obtained from section one of the Soil Conservation Service Map Unit Use File (MUUF). Every current county survey has a corresponding code, which is the county FIPS code for single whole county surveys. For partial county and multi-county surveys, codes are 600 numbers. These codes are found by searching the MUUF for state and survey area name, and are used for finding cross reference keys to specific soil information.

The specific site locators are the site ID, latitude, longitude, and approximate elevation. The site ID is an alpha-numeric code taken from the marked topo maps as received. The number includes the PSU. For sites with multiple tanks, a letter is tacked onto the end of the

ID (i.e. A, B, C, etc.) identifying each tank, so that each tank has its own unique record in the event that soil conditions may differ.

The site coordinates were determined by measuring those marked on USGS topo maps with a gridded ruler to the nearest 1/16 inch and then performing the necessary calculations. The coordinates were presented in the file in degree:minute:second format. Sites received marked on maps with insufficient scale or resolution were included with general information only (i.e. no specific coordinates). The elevation was taken from the topo map.

The Hydrologic Unit, or HU Code, is a numeric code assigned to a drainage basin or distinct hydrologic feature by the Office of Water Data Coordination. Although the HU Code is applied mainly to surface water, it is sometimes used to organize groundwater studies. An example of this is D.K. Todd's major water resource divisions in Ground-Water Resources of the United States. These major divisions correspond to the first two digits of the HU Code, as shown in Figure 1. HU Codes are available from ENVIRLOC.

B. Climate

State Climatic Divisions (SCDs) are areas within states which have similar climates. The National Weather Service has defined 353 divisions in the United States which frequently follow county boundaries. These divisions, which were retrieved from GEOCOLOGY, for survey locations, will help determine the closest applicable weather station from which to take climate data. NOAA will provide rainfall statistics to the Exposure Evaluation Division for those stations recording hourly precipitation as well as mean temperature and humidity by SCD.

C. Soil

The soil information included in the basic site file provides some parameters plus soil type keys for obtaining additional data from Soils-5, the soil data base of the Soil Conservation Service.

The Soil Map Unit is an alpha-numeric which is obtained from the Soil Conservation Service published soil surveys. The unit is found by locating the site on one of the soil maps in the county survey, usually by comparison with the marked topo map. The Soil Map Unit and the Survey Area Code are then used to extract the Soils-5 Recnumber from the Map Unit Use File (MUUF) section three. The Soils-5 Recnumber consists of the two character state abbreviation and a four digit number which together determine the record to access within the Soils-5 data base. The additional information include such parameters as permeability, pH, percent clay, etc. A sample of the available data is shown in Table H-7.

If a county or part of a county did not have a current published soil survey, a soil type inference was made using surrounding county soil surveys, making either an individual soil type inference or a major association inference as shown in the site file. Soils-5

Recnumbers were then found as before. If an inference could not be made with reasonable confidence, then no inference was made.

Additional information in the Basic Site File includes seasonal high water table, availability of C-Horizon (subsoil) parameters, and relative corrosivity to steel and concrete, all of which could be useful for the prediction of possible tank leaks. The seasonal high water table information provides a depth range, water table type, and the months of common occurrence. Availability of C-Horizon information is a yes or no indication of whether countysoil survey data include the mineral subsoil. Risk of Corrosion is a relative parameter (low, moderate, high) determined primarily by drainage class and texture, total acidity, resistivity at field capacity, and conductivity of saturated extract, as described in part 603 of the National Soils Handbook of the SCS.

D. Groundwater/Geologic

R.C. Heath divided the United States into major groundwater regions (referred to in the site file as Heath Regions) in his report "Ground-water regions of the United States". Figures 2 and 3 show the boundaries of the fifteen regions. Heath established ranges for transmissivity, hydraulic conductivity, and porosity for these groundwater regions, which may be used if actual data is not available. These ranges are very general, however, and should be used with caution.

Space is provided for the NWWA (National Water Well Association) subregion for future input. The NWWA is currently organizing hydrogeologic parameter ranges for subsets of the region of R.C. Heath.

A literature search was performed in the National Water Well Association bibliographic data base to locate articles and studies describing aquifers in the areas of interest. Most of the publications were USGS reports which contain good groundwater and geologic descriptions. These USGS publications were used to develop the groundwater file which is cross referenced in the Basic Site File.

Extensive searches were performed in the NAWDEX Ground Water Site Inventory to obtain water and well information. Site Resolution (position with respect to aquifer), Well Usuage Description (domestic, public, industrial, etc.), and Depth to Groundwater were usually obtained from the GWSI. Well sites within five minutes latitude and longitude of a survey site were used to determine the parameters at that site. If no well sites were within this radius of the LUST site, Depth to Groundwater was taken from ENVIRLOC (this appears as a range). The other literature sources previously mentioned were occasionally used when available.

The Basic Site Information File, Soils-5, the Groundwater Information File, and the future NOAA weather data. will be useful tools providing reasonable environmental scenarios to the modeller.

This will aid not only in modeling efforts for the LUST study, but for future modeling studies as well.

Table H-1. Information Source Summary (1 of 5)

Source	Parameters	Geographic Coverage and Frequency
Literature:		
County Soil Surveys USDA Soil Conservation Service	soil type, level, slope, permeability, pH, available moisture capacity, temperature, precipitation, soil texture, % fragments, sieve analysis, liquid limit plasiticity, index, shrink/swell potential, erosin factors	most US counties (down to 60 inches only)
	depth to groundwater soil bulk density, cation exchange capacity, organic content, clay content	some counties
USGS Publications		
Water Resources Data	surface water data	all US states
	observation well number, location, hydrologic unit, groundwater level, well characteristics, aquifer type, groundwater quality	most US states, site specific
Guidebooks for Fieldtrips	thickness and characterization of rocks and water bearing formations	US, site specific (usually to bedrock), info variable by state
Water Resources Bulletins	hydrogeology of principal aquifers, saturated thickness ranges, temperature, water level, characterization of core samples, analysis	US, site specific, info variable by state

Table H-1. Information Source Summary (2 of 5)

Source	Parameters	Geographic Coverage and Frequency
	of rock samples, hydraulic conductivity, specific gravity, particle size, porosity, water quality	
Water Resources Bulletin	hydrogeology of prinicipal aquifers, saturated thickness ranges, temperature, water level, characterization of core samples, analysis of rock samples, hydraulic condictivity, specific gravity, particle size, porosity, water quality	US, site specific info variable by state
Geological Circulars	soil chemistry, tranmissivity, hydraulic conductivity, thickness, sieve analysis, soil layers	US, site specific, info variable by site
Water Resources Investigations	well data, water quality, pumping and drawdown studies	US, site specific, info variable by site
Open File Reports	Water level, aquifer description	US, site specific, info variable by site
Resources of the United States D.K. Todd, 1983 Premier Press	precipitation, occurrence of groundwater, storage coefficient, evapotranspiration, base of fresh water, potentiometric contours, basement slope	US major groundwater regions, info available for most regions

Table H-1. Information Source Summary (3 of 5)

Source	Parameters	Geographic Coverage and Frequency
Statistical Abstract of the United States, 1984 US Dept. of Commerce, Bureau of Census	mean temperature, precipitation, days w/precipitation greater than 0.1 inch, average snowfall, average percent sunshine, average windspeed	selected US cities
Climatic Atlas of the United States, 1968 U.S. Dept of Commerce, Environmental Science Services Administration, Environmental Data Service	temperature, precipitation, state climatic divisions, humidity, evaporation, snowfall radiation, skycover, wind speed	US (maps)
Hourly Precipitation Data, NOAA, US Environmental Data Service (monthly publication by state)	hourly precipitation	US weather stations
Topographic Map Series, USGS, Reston, VA	elevation, coordinates	US, most areas
Ground-Water Regions of the United States, R.C. Heath, USGS Geological Survey Water-Supply Paper 2242	groundwater regions, descriptions, ranges of transmissivity, porosity, hydraulic conductivity, and recharge	US groundwater regions

Table H-1. Information Source Summary (4 of 5)

Source	Parameters	Geographic Coverage and Frequency
NOAA (National Oceanic and Atmospheric Administration)	temperature, wind speed, precipitation, state climatic division, sky cover, humidity	US weather stations, data collected variable by station
Data Bases:		
Geocology, Oak Ridge National Laboratory (contained in GEMS)	monthly temperature	US state climatic divisions
	monthly evaporation	eastern US counties
	state climatic divisions within counties	US
	soil great groups	eastern US
NAWDEX (National Water Data Exchange) Ground Water Site Inventory, USGS, Reston, VA	well description, groundwater level, water use, lithology, transmissivity, hydraulic conductivity, storage coefficient, water quality	US site specific, data variable by site
National Ground Water Information Center Data Base, National Water Well Association, Worthington, OH	bibliographic, key word search covers current literature including USGS publications	global, major emphasis in US, literature dependent

Table H-1. Information Source Summary (5 of 5)

Source	Parameters	Geographic Coverage and Frequency
ENVIRLOC, Soil/HU Code, General Software Corporation Landover, MD	approximate depth to groundwater ranges, soil parameter ranges, Hydrologic Unit Code, Heath Groundwater region number	continental US by Zip code or coordinate
Soils-5, USDA Soil Conservation Service, Washington, D.C.	essentially same information and coverage as published surveys	most US counties, info for most counties (with modern published surveys only)

Table H-2. Status of County Soil Surveys (1 of 6)

County	Survey Name	Survey Status	Year Published
Arkansas:			
Garland		Mapping in progress	
California:			
Alameda	Alameda Area (excludes western section)	Complete	1966
Los Angeles	Los Angeles County, West San Fernando Valley Area	Complete	1979
San Mateo	San Mateo Area (excludes northern section)	Complete	1961
Colorado:			
El Paso	El Paso County Area (excludes northwestern section)	Complete	1980
Teller		Mapping not started	
Connecticut:			
Hartford	Hartford County	Out of print	1962
Tolland	Tolland County	Complete	1966
Florida:			
Duval	City of Jacksonville, Duval County	Complete	1978
Illinois:			
DuPage	DuPage and Part of Cook Counties	Complete	1979
Indiana:			
Grant	Grant County	Out of print Mapping in progress	1915

Table H-2. Status of County Soil Surveys (2 of 6)

County	Survey Name	Status Survey	Year Published
Iowa:			
Pottawattamie	Pottawattamie County	Out of print	1914
		Mapping in progress	
Kansas:			
Johnson	Johnson County	Complete	1979
Waynedotte	Leavenworth and Waynedotte Counties	Complete	1977
Kentucky:			
Bullitt		Mapping in progress	
Jefferson	Jefferson County	Complete	1966
Oldham	Oldham County	Complete	1977
Minnesota:			
Ramsey	Washington and Ramsey Counties	Complete	1980
Mississippi:			
Issaquena	Issaquena County	Complete	1961
Warren	Warren County	Complete	1964
Missouri:			
Caldwell	Caldwell County	Complete	1974
Carroll	Carroll County	Out of print	1912
		Mapping in progress	
Chariton	Chariton County	Out of print	1912
Clinton	Clinton County	Complete	1983
DeKalb	DeKalb County	Complete	1977

Table H-2. Status of County Soil Surveys (3 of 6)

County	Survey Name	Survey Status	Year Published
Gentry		Mapping complete	
Montana:			
Hill		Mapping not Started	
Liberty		Mapping not started	
Toole		Mapping not started	
Nebraska:			
Arthur	Arthur and Grant Counties	Complete	1979
Blaine	Blaine County	Out of print	1954
Custer	Custer County	Complete	1982
Grant	Arthur and Grant Counties	Complete	1979
Hooker	Hooker County	Complete	1964
Logan	Logan County	Complete	1974
Loup	Loup County	Out of print	1937
McPherson	McPherson County	Complete	1969
Thomas	Thomas County	Complete	1965
New Hampshire:			
Hillsborough	Hillsborough County	Complete	1981
Rockingham	Rockingham County	Out of print	1959

Table H-2. Status of County Soil Surveys (4 of 6)

County	Survey Name	Survey Status	Year Published
New York:			
Albany	Albany County	Out of print	1942
		Mapping in progress	
Essex		Mapping not started	
Fulton		Mapping not started	
Hamilton		Mapping not started	
Queens		Mapping not started	
Rensselaer	Rensselaer County	Out of print	1937
		Mapping complete	
Ohio:			
Greene	Greene County	Complete	1978
Miami	Miami County	Complete	1978
Montgomery	Montgomery County	Complete	1976
Preble	Preble County	Complete	1969
Oregon:			
Clackamas	Clackamas County Area	Complete	1985
Rhode Island:			
Bristol	Rhode Island	Complete	1981
Kent	Rhode Island	Complete	1981
Washington	Rhode Island	Complete	1981

Table H-2. Status of County Soil Surveys (5 of 6)

County	Survey Name	Survey Status	Year Published
South Carolina:			
Lexington	Lexington County	Complete	1976
Richland	Richland County	Complete	1978
Tennessee:			
Chester		Mapping complete	
Henderson	Henderson County	Complete	1960
Madison	Madison County	Complete	1978
Texas:			
Brooks		Mapping in progress	
Collin	Collin County	Complete	1969
Harris	Harris County	Complete	1976
Hays	Comal and Hays Counties	Complete	1984
Kenedy		Mapping not started	
Travis	Travis County	Complete	1974
Willacy	Willacy County	Complete	1982
Williamson	Williamson County	Complete	1983
Utah:			
Salt Lake	Salt Lake Area (excluding eastern section)	Complete	1974
Tooele		Mapping in progress	

Table H-2. Status of County Soil Surveys (6 of 6)

County	Survey Name	Survey Status	Year Published
Washington:			
Cowlitz	Cowlitz Area (eastern part excluded)	Complete	1974
King	King County Area (eastern part excluded)	Complete	1973
Snohomish	Snohomish County Area (eastern part excluded)	Complete	1983
Wahkiakum		Mapping complete	
Wyoming:			
Campbell	Campbell County	Out of print	1955
		Mapping in progress	
Johnson	Johnson County, Southern Part	Complete	1975
Sheridan	Sheridan County	Out of print	1939
		Mapping in progress	

Table H-3. Parameters and Record Lengths included in the Basic Site Information File.

LUST Region	30
PSU	2
State FIPS	2
County FIPS	3
USGS Topo Quad	30
Scale	9
Bottom Rt Latitude	8
Bottom Rt Longitude	9
Soil Survey Area Name	80
Year Published	4
Survey Area Code	3
Site ID	11
Latitude	8
Longitude	9
Elevation (ft)	5
HU Code	10
SCD	3
Weather Station	35
Soil Map Unit	5
Series	53
Soils5 Recnumber	6
Soil Inference	14
Inference From	33
Inference Associations	56
Inference Soils5 Numbers	54
C-Horizon Info	3
High Water Table	43
Corrosivity to Steel	13
Corrosivity to Concrete	13
Heath Region	27
NWWA Subregion	23
GW & Geologic Description	207
Site Resolution	35
Well Usage Description	35
Depth to GW (ft)	7
GW Cross Reference	25

Table H-4. Basic Site Information for Arthur County, NE.

Lust Region: Central
PSU: 23
State FIPS: 031
County FIPS: 005
USGS Topo Quad Name: Arthur
Scale: 1:62500
Bottom Right Latitude: 41:30:00
Bottom Right Longitude: 101:30:00
Soil Survey Area Name: Arthur and Grant Counties
Year Published: 1977
Survey Area Code: 601

Site ID: N230000635 Latitude: 41:34:05 Longitude: 101:41:25 Elevation(ft): 3730
HU Code: 10180014 SCD: 02 Weather Station:

Soil Map Unit: VaE Series: Valentine Fine Sand
Soils5 Recnumber: NE0091
Soil Inference: Inference From:
Inference Associations:
Inference Soils5 Numbers:
C-Horizon Info: no High Water Table: GT 5.0ft
Corrosivity to Steel: To Concrete:

Heath Region: 5 High Plan NWWA Subregion:
GW and Geologic Description: Dune sand aquifers - unconsolidated fine sand and clay with shallow water table

Site Resolution: dune sand
Well Usage Description: irrigation
Depth to Groundwater(ft): 15.00
GW Cross Reference: 52

Table H-5. Basic Site Information for Grant County, IN.

Lust Region: Midwest
PSU: 17
State FIPS: 18
County FIPS: 053
USGS Topo Quad Name: Sweetser
Scale: 1:24000
Bottom Right Latitude: 40:30:00
Bottom Right Longitude: 85:45:00
Soil Survey Area Name: area not surveyed
Year Published:
Survey Area Code:
Site ID: N170001264 Latitude: 40:30:29 Longitude: 85:49:34 Elevation(ft): 860
HU Code: 5120101 SCD: 05 Weather Station:
Soil Map Unit: NA Series:
Soils5 Recnumber:
Soil Inference: Ba,Pw Inference From: Miami County, 1979 (103)
Inference Associations: Blount-Pewamo Association
Inference Soils5 Numbers: IL0014,MI0042
C-Horizon Info: yes High Water Table: 0-3.0ft,perched apparent Dec-May
Corrosivity to Steel: high To Concrete: low
Heath Region: 6 Nonglaciated Central NWWA Subregion:
GW and Geologic Description: Unconsolidated sand and gravel deposits over water bearing limestone and dolomite bedrock
Site Resolution: over unconsolidated and bedrock aquifer
Well Usage Description:
Depth to Groundwater(ft): 3.2-10
GW Cross Reference: 29

Table H-6. Basic Site Information for Duval County, FL.

Lust Region: Southeast
PSU: 07
State FIPS: 12
County FIPS: 031
USGS Topo Quad Name: Jacksonville
Scale: 1:24000
Bottom Right Latitude: 30:15:00
Bottom Right Longitude: 81:37:30
Soil Survey Area Name: City of Jacksonville, Duval County
Year Published: 1978
Survey Area Code: 031

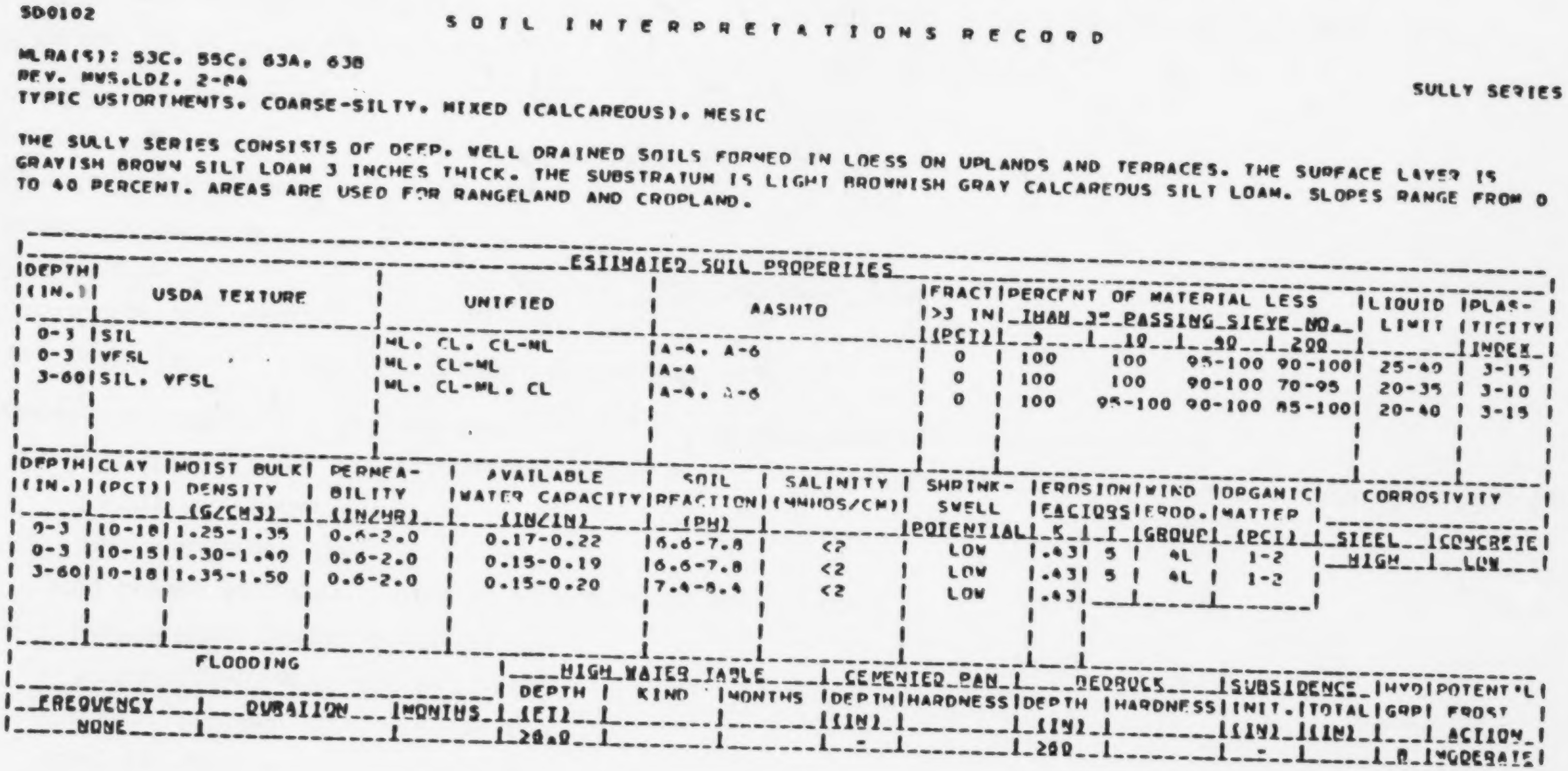
Site ID: D070000154   Latitude: 30:20:52   Longitude: 81:44:44   Elevation(ft): 20
HU Code: 3080103   SCD: 02   Weather Station:

Soil Map Unit: 26   Series: Pelham Fine Sand
Soils5 Recnumber: GA0015
Soil Inference: Inference From:
Inference Associations:
Inference Soils5 Numbers:
C-Horizon Info: no   High Water Table: 0-1.0ft, apparent Jun-May
Corrosivity to Steel: high   To Concrete: high

Heath Region: 10 Atlantic & Gulf Coastal   NWWA Subregion:
GW and Geologic Description: Layers of clay, sand, shells, and limestone, very shallow water table, springs and seeps common

Site Resolution: over shallow & Florida aquifer
Well Usage Description: irrigation, public, domestic
Depth to Groundwater(ft): 23.00
GW Cross Reference: 23

Table H-7. Example of the type of information available in Soils5.



SD0102

SOIL INTERPRETATIONS RECORD

MLRA(S): 53C, 55C, 63A, 63B
REV. MWS.LDZ, 2-84
TYPIC USTORTHENTS, COARSE-SILTY, MIXED (CALCAREOUS), MESIC

SULLY SERIES

THE SULLY SERIES CONSISTS OF DEEP, WELL DRAINED SOILS FORMED IN LOESS ON UPLANDS AND TERRACES. THE SURFACE LAYER IS GRAYISH BROWN SILT LOAM 3 INCHES THICK. THE SUBSTRATUM IS LIGHT BROWNISH GRAY CALCAREOUS SILT LOAM. SLOPES RANGE FROM 0 TO 40 PERCENT. AREAS ARE USED FOR RANGELAND AND CROPLAND.

ESTIMATED SOIL PROPERTIES

DEPTH (IN.)	USDA TEXTURE	UNIFIED	AASHTO	FRACT >3 IN (PCT)	PERCENT OF MATERIAL LESS THAN 3" PASSING SIEVE NO. 4	10	40	200	LIQUID LIMIT	PLASTICITY INDEX
0-3	SIL	ML, CL, CL-ML	A-4, A-6	0	100	100	95-100	90-100	25-40	3-15
0-3	VFSL	ML, CL-ML	A-4	0	100	100	90-100	70-95	20-35	3-10
3-60	SIL, VFSL	ML, CL-ML, CL	A-4, A-6	0	100	95-100	90-100	85-100	20-40	3-15

DEPTH (IN.)	CLAY (PCT)	MOIST BULK DENSITY (G/CM3)	PERMEABILITY (IN/HR)	AVAILABLE WATER CAPACITY (IN/IN)	SOIL REACTION (PH)	SALINITY (MMHOS/CM)	SHRINK-SWELL POTENTIAL	EROSION FACTORS K	T	WIND EROD. GROUP	ORGANIC MATTER (PCT)
0-3	10-18	1.25-1.35	0.6-2.0	0.17-0.22	6.6-7.8	<2	LOW	.43	5	4L	1-2
0-3	10-15	1.30-1.40	0.6-2.0	0.15-0.19	6.6-7.8	<2	LOW	.43	5	4L	1-2
3-60	10-18	1.35-1.50	0.6-2.0	0.15-0.20	7.4-8.4	<2	LOW	.43			

CORROSIVITY STEEL	CONCRETE
HIGH	LOW

FLOODING FREQUENCY	DURATION	MONTHS	HIGH WATER TABLE DEPTH (FT)	KIND	MONTHS	CEMENTED PAN DEPTH (IN)	HARDNESS	BEDROCK DEPTH (IN)	HARDNESS	SUBSIDENCE INIT. (IN)	TOTAL (IN)	HYD GRP	POTENT'L FROST ACTION
NONE			20.0			-		200		-		B	MODERATE

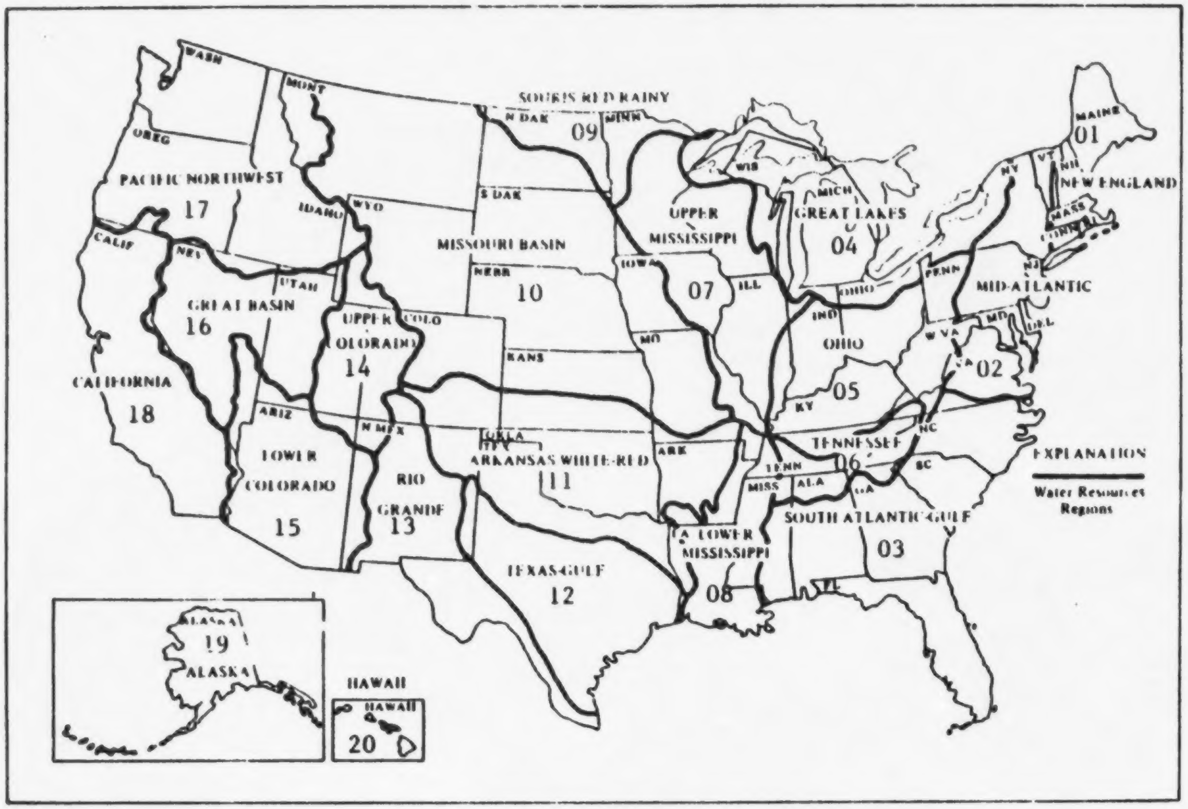

WASH
OREG
PACIFIC NORTHWEST
17
CALIF
MONT
IDAHO
WYO
NEV
UTAH
GREAT BASIN
16
CALIFORNIA
18
UPPER COLORADO
COLO
14
ARIZ
LOWER COLORADO
15
N MEX
RIO GRANDE
13
SOURIS RED RAINY
N DAK
09
MINN
S DAK
MISSOURI BASIN
NEBR
10
KANS
OKLA
ARKANSAS WHITE-RED
11
TEXAS-GULF
12
UPPER MISSISSIPPI
IOWA
07
MO
ILL
WIS
MICH
GREAT LAKES
04
IND
OHIO
05
KY
ARK
LA
LOWER MISSISSIPPI
08
TENNESSEE
06
TENN
MISS
ALA
GA
SOUTH ATLANTIC-GULF
03
SC
NC
W VA
VA
02
MD
DEL
PENN
NJ
MID-ATLANTIC
NY
VT
NH
MAINE
01
NEW ENGLAND
MASS
CONN
EXPLANATION
Water Resources Regions
ALASKA
19
HAWAII
20

Figure 1. Major surface hydrologic units, corresponding also with groundwater regions as described in Todd, 1983.

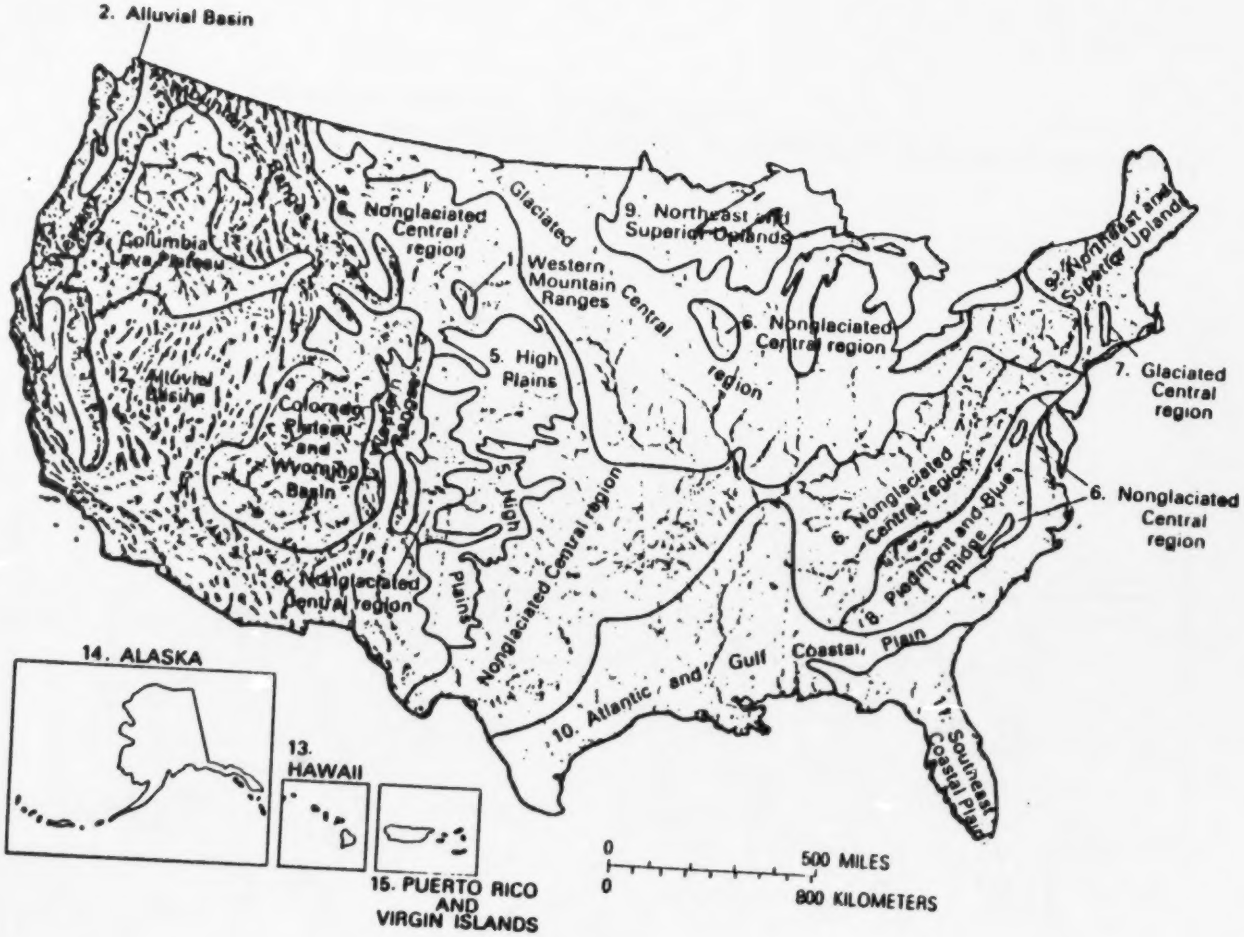

2. Alluvial Basin
1. Western Mountain Ranges
Western
3. Columbia Lava Plateau
2. Alluvial Basins
4. Colorado Plateau and Wyoming Basin
Western Mountain Ranges
6. Nonglaciated Central region
6. Nonglaciated Central region
5. High Plains
5. High Plains
Nonglaciated Central region
Glaciated Central region
1. Western Mountain Ranges
9. Northeast and Superior Uplands
6. Nonglaciated Central region
6. Nonglaciated Central region
9. Northeast and Superior Uplands
7. Glaciated Central region
6. Nonglaciated Central region
8. Piedmont and Blue Ridge
10. Atlantic and Gulf Coastal Plain
11. Southeast Coastal Plain
14. ALASKA
13. HAWAII
15. PUERTO RICO AND VIRGIN ISLANDS
0
500 MILES
0
800 KILOMETERS

Figure 2. Major groundwater regions of Heath.

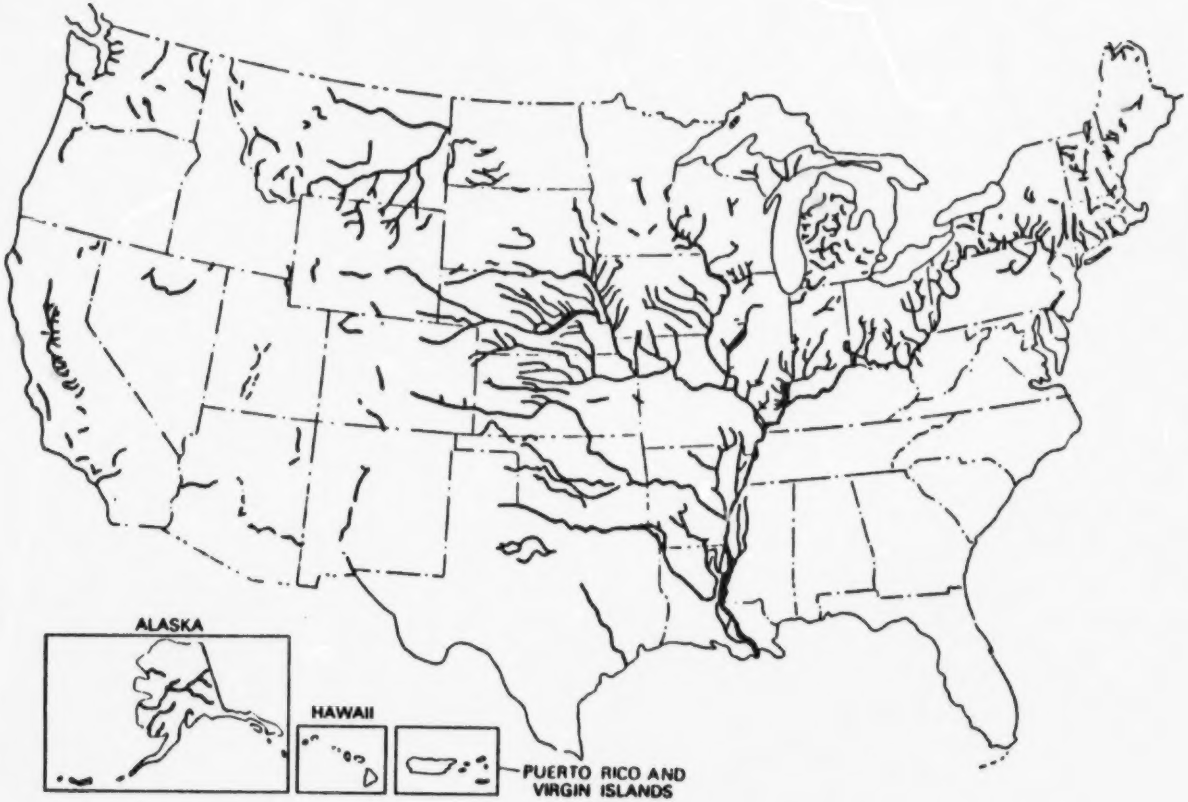

ALASKA
HAWAII
PUERTO RICO AND VIRGIN ISLANDS

Figure 3. Heath region 12 Alluvial Valleys.

APPENDIX I

MULTIVARIATE ANALYSIS

I. INTRODUCTION

While the tables presented in Section 9 provide a useful descriptive look at leaking tanks and conditions under which leaks occur, they do not take into account the simultaneous effects of many variables. To respond to this analytical need, multivariate statistical models have been developed to examine the relationship between leak status (1 = leak, 0 = no leak) [or leak rate (gallons per hour)] and various explanatory variables.

The advantage of the multivariate analysis is that it provides a method of assessing the contribution of individual explanatory factors, while simultaneously controlling for other variables. The procedures used also allow a step-wise approach (i.e., first finding the one variable that best predicts leak status [or leak rate], then the second best predictor, etc.) and a test for the statistical significance of coefficients of each variable in the model. The results of the multivariate analysis have been summarized in the next subsection so that the reader may learn the outcome of the multivariate analysis without having to go through all the mathematical details. The technical details on mathematical formulation can be found in later subsections, along with the final equations for the multiple regression and logistic regression models developed.

II. SUMMARY OF MULTIVARIATE ANALYSIS RESULTS

The major results of the modeling efforts are presented below. The reader should also note the caveates and limitations at the end of this summary.

A. Multiple Correlations

The multiple correlation coefficients (R) from the final regression models (which retained only variables with significant regression coefficients -- see Subsection C for confidence levels) were about .30 for leak status and .45 for leak rate, demonstrating low to moderate predictive ability. This corresponds to R^2 values of aboue .08 and .20, respectively. Since R^2 can be interpreted as the fraction of variance accounted for by the model, it is clear that the models do not account for most of the variance in leak status and leak rate.

B. Predictors of Leak Status

Based on the coefficients in the regression and/or logistic models, the probability that a tank system leak tends to increase for:

- Older tanks,
- Tanks with no leaded gasoline stored,
- Tanks with passive cathodic protection, and
- Tanks for which no log of deliveries is kept.

The positive relationship between leak probability and passive cathodic protection might seem surprising. A possible explanation is that passive cathodic protection tends to be used in areas which have a history of corrosion/leak problems. Another explanation could be that passive cathodic protection is strongly correlated with the storage of aviation fuel and, thus, might be a proxy for this fuel type. (The multivariate model equations for leak status may be found in Section III, which follows.)

C. Predictors of Leak Rate

Among leaking tank systems, the leak rate tends to be larger for:

- Fiberglass tanks;
- Tanks not on a concrete pad;
- Tanks both old and steel (i.e., an interaction effect)[*];
- Tanks attached to other tanks; and
- Tanks in establishments with operators trained to check for line leaks.

The above factors are not indicators of leak likelihood, but of larger leak rates among leaking tank systems. The last factor may well be a case of reverse causality -- i.e., where tank systems leak heavily, operators are trained to detect line leaks (rather than vice versa).

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[*] More precisely, fiberglass tank systems show less increase in leak rate as they get older.

D. Limitations and Caveats

In addition to the comments about the limitations of the scope of the study presented in Section 8, the following limitations and caveats apply to the multivariate analysis:

- Only business, government and military sectors are included (no farms).
- Manifolded tanks that could not be separated for tightness tests are not included.
- Although a long list of 49 potential explanatory variables were included, there are other possible variables which were not in our data base and whose effects are, therefore, not accounted for. In particular, soil characteristics were not available for analysis and use in the models. However, backfill around the tank (e.g., sand/gravel) is included and may be more relevant.
- The multivariate analysis finds "measures of association" rather than causality. Naturally, since the variables used were suspected of affecting leaking, the discovery of a statistically significant association tends to affirm a causal linkage. But the reader is cautioned that a different covariate could be the real causative factor, as in all statistical correlation studies. For example, the variable "age of tank" could represent the effects of aging, per se, or age of tank could be a proxy for different installation techniques which changed over time, or different resins used in the manufacture of fiberglass tanks in different production years.

III. MULTIVARIATE MODEL DEVELOPMENT PROCEDURE

A. Overview

Two regression models (one to predict leak status and one to predict leak rate) were developed using the variables in Table I-1 as candidate predictor variables. (Table I-1 also appears as Table 9-31 in Section 9 of this report.) The regression analysis followed a number of preliminary steps before arriving at the final models. This included elimination of variables with too many missing variables (X_{13}, X_{16}, X_{18}) and variables with nearly constant values (X_8, X_9, X_{21}, X_{23}). Stepwise regression runs were made to obtain a reduced set of variables which best predicted leak status or leak rate. Finally, individual regression coefficients were examined to ensure statistical significance. Sample sizes are shown below for the final model.

Model	Sample Size
Leak Status Regression	327
Leak Status Logistic	380
Leak Rate Regression	99

Table I-1. Simple Correlation of Leak Status with Explanatory Variables

Explanatory Variable	Meaning	Definition	Correlation(1) with Y1, Leak status (1 = Leak; 0 = No Leak)	Correlation(1) with Y2, Leak rate (gal/Hr), among leaking tanks(2)
X1	Gas Station	1 = Yes; 0 = No	-.08	-.06
X2	# Underground tanks	Number at facility	.12	.10
X3	Tank capacity	Gallons	.14	.34
X4	Average low fill level(3)	As fraction of tank capacity	-.05	-.07
$X5^2$	$(\text{Age of tank})^2$	in (years)^2	.11	-.20
X6	Leaded gasoline	1 = yes; 0 = No	-.26	-.11
X7	Diesel fuel	1 = Yes; 0 = No	.24	-.08
X8	Aviation fuel	1 = Yes; 0 = No	.13	.07
X9	Gasohol	1 = Yes; 0 = No	-.07	0
X10	Other	1 = Yes; 0 = No	.08	.29
X11	Suction pump	1 = Yes; 0 = No	.003	-.12
X12	Depth buried	Inches from surface to top of tank	.10	-.006
X13	Water level	Inches from surface to water table(4)	-.15	-.005
X15	Tank tested	1 if tested after placed in service; 0 otherwise	.03	.01
X16	Years since test	Since most recent test	.0[illegible]	-.21
X17	Tank material	1 = steel; 0 = fiberglass	.02	-.09
X18	Tank lined	1 = Yes; 0 = No	.07	.02
X19	Tank coated	1 = Yes; 0 = No	-.01	-.25
X20	Passive cathodic protection	1 = Yes; 0 = No	.10	.05
X21	Impressed current cath. protection	1 = Yes; 0 = No	0	0
X23	Other protection	1 = yes; 0 = No	-.08	0
X24	Previous tank leak	1 = Yes; 0 = No	-.05	-.04
X25	Previous line leak	1 = Yes; 0 = No	.05	.23
X26	Frequency of delivers	Number per year	-.05	-.003
X27	Sand fill	1 = Yes; 0 = No	.03	-.10
X28	Gravel fill	1 = Yes; 0 = No	.006	.16
X29	Concrete pad	1 = Yes; 0 = No	.07	-.09
X30	Packed earth pad	1 = Yes; 0 = No	.03	-.09
X31	Dist. to nearest tank or structure	(feet)	-.04	-.09

[1] Pearson's correlation coefficient; Kendall's Tau-B was also calculated for all Y1 correlations and found to be the same for nearly every variable.

[2] Using data only from individual leaking tanks with quantifiable leaks.

[3] I.e., just before product is added.

[4] At time of test.

Table I-1. Simple Correlation of Leak Status with Explanatory Variables (Continued)

Explanatory Variable	Meaning	Definition	Correlation(1) with Y1, Leak status (1 = Leak; 0 = No Leak)	Correlation(1) with Y2, Leak rate (gal/Hr), among leaking tanks(2)
X32	Interaction: age & material	(X5) (1-X17)	-.03	-.07
X33	Interaction: gasohol & material	X9 (1-X17)	0	0
X34	Permit to install	1 = Yes: 0 = No	.12	.17
X35	Permit to store	1 = Yes: 0 = No	.02	.09
X36	Average high fill level(6)	As fraction of tank capacity	-.06	-.09
XT3	Average fuel delivery	in gallons (to one tank)	.15	.23
XT4	Max. ever stored	gallons	.11	.29
XT18A	Attached to other tank	1 = Yes: 0 = No	.22	.24
XT19	Tank proximity to water table	1 = above: 2 = partially above: 3 = below: 4 = other	.13	.28
XT20	Manway with tank	1 = Yes; 0 = No	.19	.13
XT36	Not self-installed	1 = Yes; 0 = No	.12	.12
XB5	Remote gauge	1 = Yes; 0 = No	-.005	.05
XB19	Log of deliveries	1 = Yes; 0 = No	-.03	.002
XC7	Any abandoned tank(5)	1 = Yes; 0 = No	-.03	.03
XC8	# Abandoned tanks	(coded as zero if none)	.12	-.09
XF1A	Corrosion prevention equip./ mat.	1 = Yes; 0 = No	-.02	-.12
XG2D	Trained to check pump	1 = Yes; 0 = No	.14	.24
XG2E	Trained to check line leaks	1 = Yes; 0 = No	.10	.18
XG2F	Trained to check leak prevention	1 = Yes; 0 = No	.10	.15
XG2G	Trained to check leak monitoring	1 = Yes: 0 = No	.15	.17

[5] At that facility.

[6] I.e., Just after product is delivered.

B. Multiple Regression Models

Two models were constructed:

[1]	Leak Status Model: (among all tanks with tightness test)	Dependent Variable, $Y1$ = 1 if leak 0 otherwise
[2]	Leak Rate Model: (among leaking tank systems only)	Dependent Variable, $Y2$ = leak rate in gal/hr

Both models were run using the predictor variables in Table I-1. The general form of the model is:

$$Y = b_o + b_1X_1 + b_2X_2 + \ldots$$

where a few of the variables were interaction terms and the b's are regression coefficients estimated by a least-squares procedure. In addition, a non-linear transformation was used for one of the X variables. Age^2 was used rather than Age because data plots suggested a non-linear increase in the percentage of tanks that leak as a function of age.

C. Logistic Regression Model

For the leak status model, an alternative logistic regression model was run. The dependent variable can be reexpressed as an odds ratio*, in the form:

$$[1a]\ \log \frac{\text{Probability of Leaking Tank}}{\text{Probability of Tight Tank}} =$$

$$b_o + b_1X_1 + b_2X_x + \ldots$$

This alternative formulation of Model [1] should more nearly satisfy the homogeneity of variance assumption for regression.

The coefficients (b's) for the Logistic Model are estimated by maximum-likelihood methods rather than least-squares.

IV. FINAL MULTIVARIATE MODELS

Using the procedures defined above, linear and logistic regression models were developed for leak status. For leak rate, a separate linear regression model was developed. The final models appear below.

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*The assumed underlying model for the logistic regression is $Y = 1/[(1 + \exp(-b_0 - b_1X_1 - b_2X_2 \ldots.)]$. From this expression it can be shown that $\log [Y/(1 - Y)] = b_o + b_1X_1 + b_2X_2 + \ldots$ In this equation Y is the probability that the tank system leaks and 1 - Y is the probability that it does not leak.

Leak Status Models

[1] Regression Model*:

$$Y1 = .22 + .00019\ X_5^{2\,**} - .25\ X_6 + .0044\ X_{12}^{***} + .18\ X_{20}$$

[1a] Logistic Model****:

$$\log \frac{\text{Probability of Leak}}{\text{Probability no Leak}} = 1.3 - .63\ X_6 -.0\ 17\ X_{12} - .38\ X_{B19}$$

---

*All coefficients significant at the 94 percent confidence level or better (except coefficient of X_{20} at 78 percent confidence level).

**(Age)^2 was used rather than Age because this non-linear transformation showed a stronger correlation with leak status.

***The regression model found a + coefficient, but the logistic model found a - coefficient. This may be a case of X_{12}'s collinearity with other variables. However, no strong collinearities were detected with X_{12}. (See Tables I-2 and I-3 in Section V.) Therefore, the relationship with X_{12}, depth tank is buried, is inconclusive based on this mixed result.

****All coefficients significant at the 94 percent confidence level or better.

[2] Leak Rate Model*****:

$$Y2 = .91 - .67\ X_{17} - .54\ X_{29} - .0068\ X_{32}^{******} + .62\ X_{T18A} + .25\ X_{G2E}$$

The reliability of the model was examined in several ways. For the regression models, the multiple correlation coefficient, R, provides some overall measure of the predictive ability of the model. These results are shown below.

	Multiple Correlation Coefficient, R		R^2	
Equation	Unadjusted	Adjusted	Unadjusted	Adjusted
[1]	.30	.29	.093	.081
[2]	.50	.45	.25	.20

*****All coefficients significant at the 97 percent confidence level or better.

******This is an interaction term which was included to capture the more than additive effect of age and material type together.

The "adjusted" values of R and R^2 adjust for degrees of freedom in the model and, therefore, provide a better estimate of how reliably the model might predict leak status and leak rate for other tank systems beyond the modeling data set. The R^2 term can be interpreted as the proportion of the variance in Y that can be explained for by the model. Thus, the model is able to account for less than 10 percent of the total variance in leak status and only about 20 percent the variance in leak rate.

The reliability of the coefficients of the X's in equations [1], [1a] and [2] were also examined to ensure that the value is not likely to be a chance occurrence. The probability that these coefficients are not chance occurrences is 94 percent or more for each of 9 of the 10 parameters in these equations. The remaining coefficient had a 78 percent probability of being a non-chance occurrence (i.e., there is a very low probability of the observed coefficient occurring if its true value were zero). It should be noted that these probabilities of non-chance occurrence applies one variable at a time -- i.e., with many variables tried in the model, the probability of at least one chance selection of a variable increases.

V. RELATIONSHIP BETWEEN EXPLANATORY VARIABLES (COLLINEARITY)

Multicollinearity frequently exists in large data sets. Pairwise collinearity is one sample form, and is relatively easy to visualize. In order to test for such "first order" collinearity in the models, the correlations between all pairs of independent or predictor variables (i.e., X's) were computed. The results shown in Table I-2 indicate low pairwise collinearity, except for X_{17} (tank material) and X_{32} = [(1 - tank

Table I-2. Collinearity (intercollelation) of X's in models

A. Leak status regression and logistic models -- Pearsons Correlation Coefficient between explanatory variables

	X_5^2	X_6	X_{12}	X_{20}	X_{B19}
X_5^2	1	-.03	-.07	-.08	.10
X_6		1	-.06	-.12	.002
X_{12}			1	.07	.09
X_{20}				1	-.04
X_{B19}					1

B. Leak rate regression model -- Pearson's Correlation Coefficient between explanatory variables

	X_{17}	X_{29}	X_{32}	X_{T18A}	X_{G2E}
X_{17}	1	.09	-.80	.13	.05
X_{29}		1	-.07	.38	.08
X_{32}			1	-.10	-.11
X_{T18A}				1	-.02
X_{G2E}					1

material) x $(\text{Age})^2$] in the leak rate model (correlation of -.80). The variable, X_{32}, is an interaction term. The correlation of X_{17} with X_{32} is close to the correlation of Age^2 with $-\text{Age}^2$. Therefore, a large intercorrelation would be expected.

Table I-3 shows correlations between variables in the models and variables not in the models. (Variables with small correlations, less than .20, are not included.) Any large correlations could be considered as proxies (or substitutes) for the model variable with which they are strongly correlated. For example, in the leak status model, passive cathodic protection (X_{20}) is strongly correlated (correlation coefficient = .62) with aviation fuel (X_8). Therefore, the apparent increase in the likelihood of a leak with passive cathodic protection, might be due, in large measure, to its relationship with aviation fuel storage.

Table I-3. Correlation Between Model X's and X's not in the Model

A. Leak Status Model

Model X	Non Model X's	Pearson's Correlation Coefficients (≥ .20)
X_5^2, (Age of Tanks)^2		None
X_6, Leaded gasoline	X_7 (Diesel fuel)	-.39
X_{12}, Depth buried		None
X_{20}, Passive cathodic	X_2 (# Underground tanks)	.33
	X_8 (Aviation fuel)	.62
	X_{18} (Tank lined)	.34
	X_{29} (Concrete pool)	.38
	X_{T18A} (Attached to other tank)	.29
	X_{T20} (Manway with tank)	.41
	X_{G2E} (Trained to chek line leaks)	.24
	X_{G2F} (Trained in leak protection)	.27
	X_{G2H} (Trained in leak monitoring)	.31
X_{B19}, Log of deliveries	X_{13} (Water level)	.30
	X_{16} (Years since test)	.34
	X_{34} (Permit to install)	.20
	X_{35} (Permit to store)	.20

B. Leak Rate Model

Model X	Non Model X's	Pearson's Correlation Coefficients (≥ .20)
X_{17}, Tank material	X_1 (Gas station)	-.21
	X_7 (Diesel fuel)	.22
	X_{11} (Suction pump)	.42
	X_{13} (Water level)	-.29
	X_{15} (Tank tested)	-.28
	X_{16} (Years since test)	-.37
	X_{18} (Tank lined)	-.35
	X_{19} (Tank coated)	.66
	X_{32} (Interaction: Age^2 & material)	-.80
X_{29}, Concrete pad	X_2 (# Underground tanks)	.46
	X_4 (Average low fill level)	.24
	X_{16} (Years since test)	-.48
	X_{20} (Passive cathodic protection)	.26
	X_{30} (Packed earth pad)	-.20
	X_{34} (Permit to install)	.24
	X_{36} (Average high fill level)	.28
	X_{T3} (Average fuel delivery)	.20
	X_{T18A} (Attached to other tank)	.38
	X_{T20} (Manway with tank)	.52
	X_{G2H} (Trained in leak monitoring)	.24
X_{32}, Interaction: Age^2 & material	X_{11} (Suction pump)	-.29
	X_{15} (Tank capacity)	.26
	X_{16} (Years since test)	.49
	X_{17} (Tank material)	-.80
	X_{18} (Tank lined)	.53
	X_{19} (Tank coated)	-.54
X_{T18A}, Attached to other tank	X_2 (# underground tanks)	.48
	X_3 (Tank capacity)	.22
	X_7 (Diesel fuel)	.23
	X_{13} (Water level)	-.30
	X_{16} (Years since test)	-.23
	X_{25} (Previous line leak)	.28
	X_{29} (Concrete pad)	.38
	X_{30} (Packed earth pad)	-.29
	X_{34} (Permit to install)	.29
	X_{35} (Permit to store)	.25
	X_{36} (Average high fill level)	.25
	X_{T3} (Average fuel delivery)	.35
	X_{T4} (Maximum ever stored)	.33
	X_{T20} (Manway with tank)	.40
	X_{G2D} (Trained to check pump)	.24

Leak Rate Model (Continued)

Model X	Non Model X's	Pearson's Correlation Coefficients ($\geq .20$)
X_{G2E}, Trained to check line leaks	X_2 (# underground tanks)	.25
	X_7 (Diesel fuel)	-.25
	X_8 (Aviation fuel)	.25
	X_{10} (Other fuel)	.41
	X_{16} (Years since test)	-.44
	X_{28} (Gravel fill)	.21
	X_{T19} (Tank proximity to water table)	.39
	X_{T20} (Manway with tank)	.22
	X_{G2D} (Trained to check pump)	.40
	X_{G2F} (Trained in leak protection)	.89
	X_{G2H} (Trained in leak monitoring)	.68